

3. SUMMARY OF WESTERN NORTH PACIFIC AND NORTH INDIAN OCEAN TROPICAL CYCLONES

3.1 GENERAL

The calendar year 1989 was a very busy year. JTWC issued warnings on a total of 35 tropical depressions, tropical storms and typhoons in the western North Pacific — 5 super typhoons, 16 less intense typhoons, 10 tropical storms and 4 tropical depressions — the most tropical cyclones since 1974 and the most typhoons since 1972. An extensive post analysis indicated that dissipating Ken (13W) and developing Lola (14W) merged into a single system, thus the total of 36 numbered cyclones was revised to 35 (Table 3-1). In any case, this is more than the climatological mean of 31 tropical cyclones in the western North Pacific (Table 3-2). The North Indian Ocean was fairly inactive with only 3 tropical cyclones occurring there — below the 5 per year average. During 1989, warnings were issued on a total of 37* Northern Hemisphere tropical cyclones. A chronology of western North Pacific and North Indian Ocean tropical cyclones is provided in Figure 3-1.

For the year, JTWC was in warning status 154 days compared to 114 in 1988. Again, considering only the western North Pacific, there were 46 days when the Center issued warnings on two cyclones and 9 days

when it warned on three cyclones (Table 3-3). When the North Indian Ocean is included, there were a total of 167 days with warnings on one cyclone, 49 days with warnings on two cyclones, and 9 days with warnings on three. There were no days when warnings were issued on four or five tropical cyclones at once. Thus, JTWC was in Northern Hemisphere warning status 40% of the year; it was warning on two or more tropical cyclones during 58 days or 16% of the year.

JTWC issued 710 warnings on 35 western North Pacific tropical cyclones, 147 more than in 1987 and 239 more than last year. In addition, the Center put out 44 warnings on North Indian Ocean tropical cyclones, for a grand total of 754 Northern Hemisphere warnings. There were 51 initial Tropical Cyclone Formation Alerts issued on western North Pacific tropical disturbances (Table 3-4) and 8 on disturbances in the North Indian Ocean. Three out of the 35 significant tropical cyclones that developed in the western North Pacific did so without Formation Alerts. Alerts were issued on all tropical cyclones that formed in the North Indian Ocean. Tropical Cyclone 32W (Gay) was already in warning status when it entered the Bay of Bengal from the Gulf of Thailand.

* TC-32W (Gay) counted only once.

TABLE 3-1

**WESTERN NORTH PACIFIC
SIGNIFICANT TROPICAL CYCLONES
FOR 1989**

TROPICAL CYCLONE	PERIOD OF WARNING	NUMBER OF WARNINGS ISSUED	MAXIMUM SURFACE WINDS KT (M/SEC)	ESTIMATED MSLP (MB)
(01W) TS WINONA	18 JAN - 19 JAN	5	55 (28)	984
(01W) TS WINONA*	20 JAN - 21 JAN	8	30 (15)	1000
(02W) STY ANDY	17 APR - 24 APR	26	140 (72)	898
(03W) TY BRENDA	15 MAY - 20 MAY	20	75 (39)	967
(04W) TY CECIL	22 MAY - 24 MAY	9	75 (39)	967
(05W) TY DOT	05 JUN - 11 JUN	25	100 (51)	944
(06W) TS ELLIS	20 JUN - 20 JUN	2	25 (13)	1002
(06W) TS ELLIS*	22 JUN - 23 JUN	4	35 (18)	997
(07W) TS FAYE	06 JUL - 11 JUL	21	55 (28)	980
(08W) STY GORDON	11 JUL - 18 JUL	30	135 (69)	898†
(09W) TS HOPE	16 JUL - 21 JUL	21	55 (28)	984
(10W) TS IRVING	21 JUL - 24 JUL	14	55 (28)	984
(11W) TY JUDY	22 JUL - 29 JUL	28	95 (49)	949
(12W) TD 12W	29 JUL - 30 JUL	3	30 (15)	1000
(13W-14W) TS KEN-LOLA	30 JUL - 04 AUG	23	50 (26)	982†
(15W) TY MAC	01 AUG - 07 AUG	28	80 (41)	963
(16W) TY OWEN	11 AUG - 18 AUG	28	75 (39)	967
(17W) TY NANCY	11 AUG - 16 AUG	22	75 (39)	967
(18W) TS PEGGY	16 AUG - 18 AUG	9	35 (18)	997
(19W) TD 19W	17 AUG - 19 AUG	6	30 (15)	1000
(20W) TS ROGER	24 AUG - 28 AUG	14	50 (26)	983†
(21W) TD 21W	25 AUG - 28 AUG	7	30 (15)	1000
(22W) TY SARAH	06 SEP - 14 SEP	33	125 (64)	916
(23W) TS TIP	09 SEP - 13 SEP	20	50 (26)	987
(24W) TS VERA	12 SEP - 16 SEP	16	50 (26)	987
(25W) TY WAYNE	17 SEP - 20 SEP	12	65 (33)	976
(26W) STY ANGELA	29 SEP - 10 OCT	46	130 (67)	910
(27W) TY BRIAN	30 SEP - 03 OCT	13	80 (41)	963
(28W) TY COLLEEN	01 OCT - 08 OCT	27	80 (41)	963
(29W) TY DAN	08 OCT - 13 OCT	21	70 (36)	972
(30W) STY ELSIE	14 OCT - 22 OCT	34**	140 (72)	898
(31W) TY FORREST	22 OCT - 29 OCT	30	95 (49)	949
(32W) TY GAY	02 NOV - 04 NOV	9***	100 (51)	943
(33W) TY HUNT	16 NOV - 23 NOV	27	90 (46)	954
(34W) STY IRMA	21 NOV - 22 NOV	3	25 (13)	1002
(34W) STY IRMA*	25 NOV - 04 DEC	36	140 (72)	898
(35W) TD 35W	07 DEC - 09 DEC	9	30 (15)	1000
(36W) TY JACK	20 DEC - 28 DEC	21	125 (64)	916

TOTAL: 710

* REGENERATED

** FOUR ISSUED BY AJTWC.

*** WARNINGS IN WESTPAC BASIN. SEE TABLE 3-5 FOR WARNINGS IN INDIAN OCEAN.

† BASED ON SYNOPTIC DATA.

The criteria used in Table 3-2 are as follows:

1. If a tropical cyclone was first warned on during the last two days of a particular month and continued into the next month for longer than two days, then that system was attributed to the second month.
2. If a tropical cyclone was warned on prior to the last two days of a month, it was attributed to the first month, regardless of how long the system lasted.
3. If a tropical cyclone began on the last day of the month and ended on the first day of the next month, that system was attributed to the first month. However, if a tropical cyclone began on the last day of the month and continued into the next month for only two days, then it was attributed to the second month.

TABLE 3-2 LEGEND

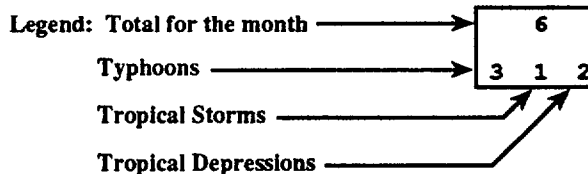


TABLE 3-2 WESTERN NORTH PACIFIC TROPICAL CYCLONE DISTRIBUTION

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTALS
1959	0	1	1	1	0	1	3	8	9	3	2	2	31
	000	010	010	100	000	001	111	512	423	210	200	200	17 7 7
1960	1	0	1	1	1	3	3	9	5	4	1	1	30
	001	000	001	100	010	210	210	810	041	400	100	100	19 8 3
1961	1	1	1	1	4	6	5	7	6	7	2	1	42
	010	010	100	010	211	114	320	313	510	322	101	100	20 11 11
1962	0	1	0	1	3	0	8	8	7	5	4	2	39
	000	010	000	100	201	000	512	701	313	311	301	020	24 6 9
1963	0	0	1	1	0	4	5	4	4	6	0	3	28
	000	000	001	100	000	310	311	301	220	510	000	210	19 6 3
1964	0	0	0	0	3	2	8	8	8	7	6	2	44
	000	000	000	000	201	200	611	350	521	331	420	101	26 13 5
1965	2	2	1	1	2	4	6	7	9	3	2	1	40
	110	020	010	100	101	310	411	322	531	201	110	010	21 13 6
1966	0	0	0	1	2	1	4	9	10	4	5	2	38
	000	000	000	100	200	100	310	531	532	112	122	101	20 10 8
1967	1	0	2	1	1	1	8	10	8	4	4	1	41
	010	000	110	100	010	100	332	343	530	211	400	010	20 15 6
1968	0	1	0	1	0	4	3	8	4	6	4	0	31
	000	001	000	100	000	202	120	341	400	510	400	000	20 7 4
1969	1	0	1	1	0	0	3	3	6	5	2	1	23
	100	000	010	100	000	000	210	210	204	410	110	010	13 6 4
1970	0	1	0	0	0	2	3	7	4	6	4	0	27
	000	100	000	000	000	110	021	421	220	321	130	000	12 12 3
1971	1	0	1	2	5	2	8	5	7	4	2	0	37
	010	000	010	200	230	200	620	311	511	310	110	000	24 11 2
1972	1	0	1	0	0	4	5	5	6	5	2	3	32
	100	000	001	000	000	220	410	320	411	410	200	210	22 8 2
1973	0	0	0	0	0	0	7	6	3	4	3	0	23
	000	000	000	000	000	000	430	231	201	400	030	000	12 9 2
1974	1	0	1	1	1	4	5	7	5	4	4	2	35
	010	000	010	010	100	121	230	232	320	400	220	020	15 17 3
1975	1	0	0	1	0	0	1	6	5	6	3	2	25
	100	000	000	001	000	000	010	411	410	321	210	002	14 6 5
1976	1	1	0	2	2	2	4	4	5	0	2	2	25
	100	010	000	110	200	200	220	130	410	000	110	020	14 11 0
1977	0	0	1	0	1	1	4	2	5	4	2	1	21
	000	000	010	000	001	010	301	020	230	310	200	100	11 8 2
1978	1	0	0	1	0	3	4	8	4	7	4	0	32
	010	000	000	100	000	030	310	341	310	412	121	000	15 13 4
1979	1	0	1	1	2	0	5	4	6	3	2	3	28
	100	000	100	100	011	000	221	202	330	210	110	111	14 9 5
1980	0	0	1	1	4	1	5	3	7	4	1	1	28
	000	000	001	010	220	010	311	201	511	220	100	010	15 9 4
1981	0	0	1	1	1	2	5	8	4	2	3	2	29
	000	000	100	010	010	200	230	251	400	110	210	200	16 12 1
1982	0	0	3	0	1	3	4	5	6	4	1	1	28
	000	000	210	000	100	120	220	500	321	301	100	100	19 7 2
1983	0	0	0	0	0	1	3	6	3	5	5	2	25
	000	000	000	000	000	010	300	231	111	320	320	020	12 11 2
1984	0	0	0	0	0	2	5	7	4	8	3	1	30
	000	000	000	000	000	020	410	232	130	521	300	100	16 11 3
1985	2	0	0	0	1	3	1	7	5	5	1	2	27
	020	000	000	000	100	201	100	520	320	410	010	110	17 9 1
1986	0	1	0	1	2	2	2	5	2	5	4	3	27
	000	100	000	100	110	110	200	410	200	320	220	210	19 8 0
1987	1	0	0	1	0	2	4	4	7	2	3	1	25
	100	000	000	010	000	110	400	310	511	200	120	100	18 6 1
1988	1	0	0	0	1	3	2	5	8	4	2	1	27
	100	000	000	000	100	111	110	230	260	400	200	010	14 12 1
1989	1	0	0	1	2	2	6	8	4	6	3	2	35
	010	000	000	100	200	110	231	332	220	600	300	101	21 10 4
(1959-1989)													
MEAN:	0.6	0.3	0.6	0.7	1.3	2.1	4.5	6.2	5.7	4.6	2.8	1.5	30.8
CASES:	18	9	18	23	39	65	140	193	176	142	86	45	954

Figure 3-1. Chronology of western North Pacific and North Indian Ocean tropical cyclones for 1989.

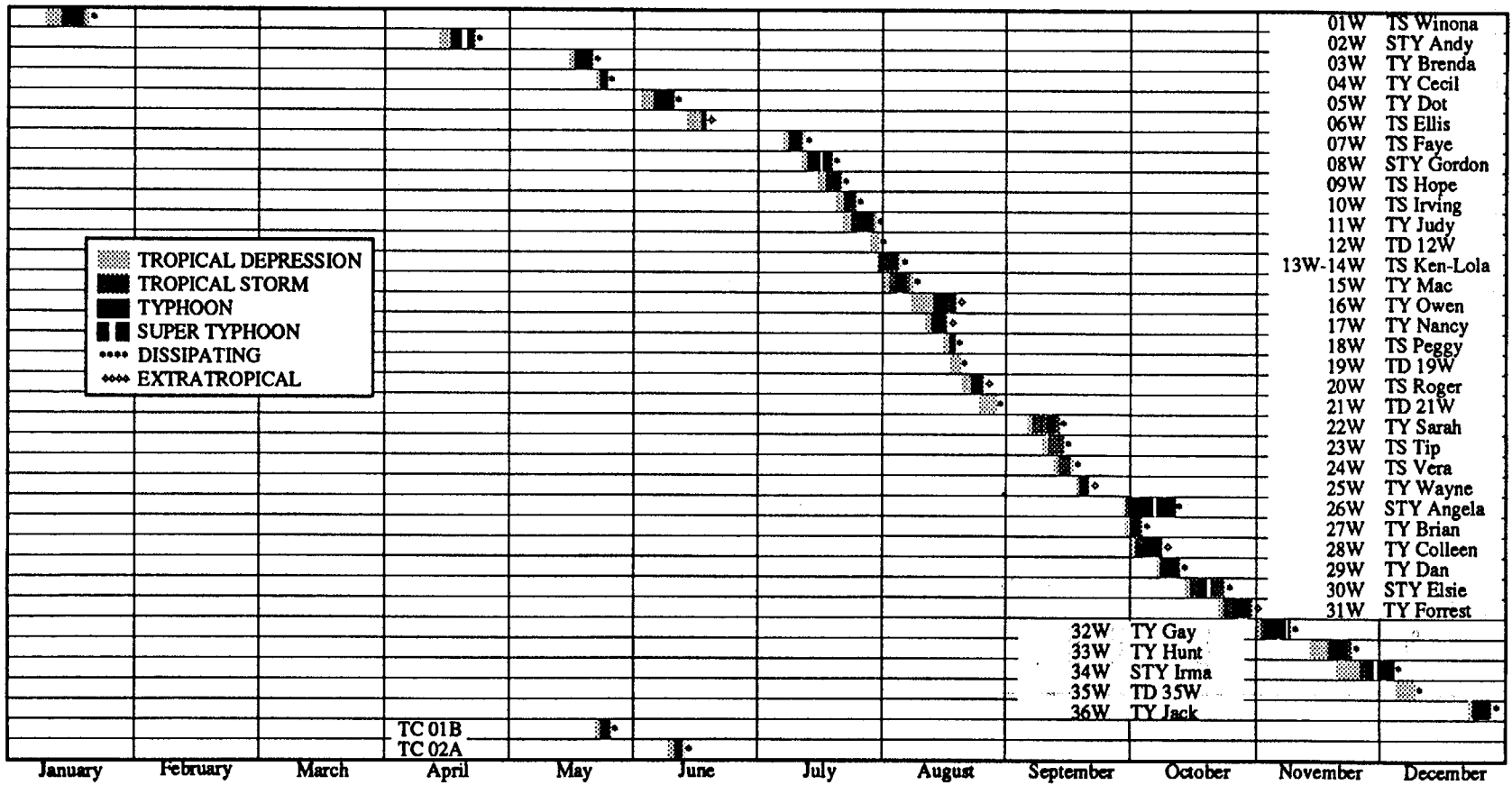


TABLE 3-3

WESTERN NORTH PACIFIC TROPICAL CYCLONES

TYPHOONS
(1945 - 1958)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTALS
MEAN:	0.4	0.1	0.3	0.4	0.7	1.1	2.0	2.9	3.2	2.4	2.0	0.9	16.3
CASES:	5	1	4	5	10	15	28	41	45	34	28	12	228

(1959 - 1989)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTALS
MEAN:	0.3	0.1	0.2	0.5	0.7	1.0	2.7	3.2	3.2	3.1	1.7	0.7	17.4
CASES:	8	2	6	16	22	32	83	99	100	97	53	21	539

TROPICAL STORMS AND TYPHOONS
(1945 - 1958)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTALS
MEAN:	0.4	0.1	0.4	0.5	0.8	1.6	3.0	3.9	4.1	3.3	2.8	1.1	22.0
CASES:	6	1	6	7	11	22	42	54	58	46	39	16	308

(1959 - 1989)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTALS
MEAN:	0.5	0.3	0.5	0.7	1.0	1.8	4.1	5.3	5.0	4.1	2.6	1.3	27.6
CASES:	17	9	14	22	33	55	127	166	154	128	81	39	855

FORMATION ALERTS: 32 OF 51 INITIAL FORMATION ALERTS DEVELOPED INTO SIGNIFICANT TROPICAL CYCLONES (NOT INCLUDING THREE ON SYSTEMS THAT REGENERATED). TROPICAL CYCLONE FORMATION ALERTS WERE NOT ISSUED FOR TROPICAL CYCLONES 08W, 25W AND 34W.

WARNINGS DAYS:

NUMBER OF CALENDAR WARNING DAYS: 154

NUMBER OF CALENDAR WARNING DAYS WITH TWO TROPICAL CYCLONES: 46

NUMBER OF CALENDAR WARNING DAYS WITH THREE TROPICAL CYCLONES: 9

TABLE 3-4

TROPICAL CYCLONE FORMATION ALERTS
WESTERN NORTH PACIFIC OCEAN

YEAR	INITIAL TCFAS	TROPICAL CYCLONES WITH TCFAS	TOTAL TROPICAL CYCLONES	FALSE ALARM RATE
1975	34	25	25	26%
1976	34	25	25	26%
1977	26	20	21	23%
1978	32	27	32	16%
1979	27	23	28	15%
1980	37	28	28	24%
1981	29	28	29	3%
1982	36	26	28	28%
1983	31	25	25	19%
1984	37	30	30	19%
1985	39	26	27	33%
1986	38	27	27	29%
1987	31	24	25	23%
1988	33	26	27	21%
1989	51	32	35	32%
(1975-1989)				
MEAN:	34.3	26.1	27.5	23.9%
TOTALS:	515	392	412	

3.2 WESTERN NORTH PACIFIC TROPICAL CYCLONES

1989 was unique in many regards. The monsoon trough was very active, even into November. Because the trough was extremely broad and because of the abnormally large diurnal fluctuations in convection, disturbances were slow to develop to intensities above 30 to 40 kt (15 to 20 m/sec). As a result, JTWC used the new 36-hour Tropical Depression Warning on systems not expected to reach tropical storm intensity within 48 hours. The mid-tropospheric ridge was narrow — averaging less than 250 nm (465 km). This made forecasts, even for straight running tropical cyclones difficult. There were a large number of erratically moving cyclones with tracks containing several bifurcation points where difficult forecast decisions had to be made as to significant changes in direction of motion. Several tropical cyclones stalled for prolonged periods of time. Some examples are Typhoons Gay (32W), Irma (34W), Mac (15W) and Jack (36W), among others. In fact, Jack (36W) sat 175 nm (325 km) directly east of Guam for nearly two days. JTWC experienced several occasions where tropical cyclones engaged in binary interaction with each other or with other circulations in the environment. Most notable was the interaction between Typhoons Owen (16W), Nancy (17W) and towards the end Tropical Storm Peggy (18W). The Tropical Upper-Tropospheric Trough (TUTT) was extremely active and played a major role in the development, intensification and movement of numerous tropical cyclones. Of particular interest was Typhoon Gordon (08W) which actually developed explosively from a thunderstorm that built beneath, and directly up into a cold-cored TUTT low aloft. And finally, 1989 had a large number of very compact, yet very intense typhoons. The presence of Tropical Cyclone 32W (Gay) with super typhoon intensity in the Bay of Bengal was a rare occurrence. The variety of synoptic influences on the 1989 tropical cyclone season made it one of the most unique and challenging in JTWC's 30-year history.

JANUARY THROUGH JUNE

The first western North Pacific tropical cyclone of 1989, **Winona (01W)**, quietly began in the eastern North Pacific southeast of the Hawaiian Islands. The system was unusual because of its compact size and persistence. In two weeks it traveled over 5500 nm (10,185 km) before finally dissipating in the Philippine Islands. Following Tropical Storm Winona (01W), there was a long break in activity until mid-April when **Andy (02W)** developed. Super Typhoon Andy (02W) was the second typhoon in the past nine years to form in April, the first super typhoon of 1989, and the first typhoon of the year to seriously threaten Guam. It developed very slowly, and after recurving at the extremely low latitude of 10° north, passed 70 nm (130 km) southeast of Guam. A month later **Brenda (03W)**, the first of two typhoons to form in May, generated in the western Caroline Islands, moved northwestward across the central Philippine Islands, and then made landfall in China. It was the second of eleven tropical cyclones to cross the Philippines during the year. An extensive monsoon trough spread across the Bay of Bengal into the South China Sea. Typhoon Brenda (03W) formed at the end of the trough. As Brenda (03W) moved northwestward and dissipated over southern China, it left behind an area of enhanced low-level southwesterly flow. Typhoon **Cecil (04W)** developed in the South China Sea in the wake of the enhanced flow from Typhoon Brenda (03W). After Cecil (04W) churned across the South China Sea and into Vietnam during the last week of May, the tropics were relatively quiet for two weeks. Then came Typhoon **Dot (05W)**, the first of two significant tropical cyclones in June. Dot (05W) formed in low latitudes south of the central Caroline islands, moved steadily west-northwestward and crossed the Philippine Islands. It reached typhoon intensity in the South China Sea and eventually dissipated over northern Vietnam. The second tropical cyclone to form in June, Tropical Storm **Ellis (06W)** interrupted the series of "straight runners" that occurred from Brenda (03W) through Dot (05W). The asymmetric displace-

ment of a broad area of gale force winds away and to the east of the low-level circulation center accompanied Ellis (06W). After five days as a poorly defined system, Ellis (06W) briefly peaked at tropical storm intensity before becoming extratropical and making landfall in Japan.

JULY

After another two-week break in activity, a surge in the southwest monsoon caused widespread convective activity in the area west of the Mariana Islands, culminating in the genesis of **Faye (07W)**, the first of seven tropical cyclones to form in July. Faye (07W) intensified at a normal rate as it tracked west-northwestward towards the Philippines. The cyclone weakened as it crossed north-central Luzon and reintensified slightly in the South China Sea. It weakened again in the central South China Sea, and crossed the island of Hainan before making landfall on the coast of northern Vietnam. At the start of the second week of July, while Tropical Storm Faye (07W) was affecting the Philippine Islands and the Tropical Upper-Tropospheric Trough (TUTT) was influencing weather near Wake Island, the second super typhoon of the year, **Gordon (08W)**, developed. It was unique in that it developed from a single cumulonimbus directly beneath a cyclonic cell in the TUTT. The cumulonimbus was initially small, but underwent a dramatic rapid, almost explosive, deepening phase. **Hope (09W)** generated in the wake of Gordon (08W) in a broad area of convection enhanced by divergence aloft associated with a TUTT cell. Hope (09W) failed to develop to typhoon intensity as a result of the upper-level shear caused by the outflow from Super Typhoon Gordon (08W). During its life, Hope (09W) moved generally northwestward, occasionally "stair stepping" in response to the passage of a series of mid-latitude short-wave troughs. Although no binary interaction was apparent, the tropical cyclone tracked along the periphery of Gordon's (08W) low-level circulation for most of its lifetime. As Super Typhoon Gordon (08W) was about to make

landfall on the coast of China and Tropical Storm Hope (09W) was reaching peak intensity, **Irving (10W)** formed in the monsoon trough near the southwestern Caroline Islands. Tropical Storm Irving (10W) was the fourth tropical cyclone of 1989 to cross the South China Sea and the last to enter the South China Sea until Typhoon Brian (27W) late in September. Irving was short-lived and actually reached its maximum intensity as it made landfall on the coast of northern Vietnam. The day after Irving (10W) developed in the western Caroline Islands, **Judy (11W)** developed in the monsoon trough just west of Guam. The second of two typhoons to develop during the month of July, Judy (11W), followed a north-oriented track with a critical turn to the northwest, just to the south of Honshu. It brushed by the southern coast of Kyushu, made landfall on the south coast of the Korean Peninsula and dissipated rapidly. After a major track change on 26 July, it took JTWC a day to get the forecast back on track to the northwest. This situation highlighted the value of the alternate scenario and rapid telephone communications between the customer and the forecaster when forecast difficulties arise. While Typhoon Judy (11W) was tracking northwestward towards Korea, an associated area of deep convection became persistent to the south-southeast in the monsoon trough that had already proven itself the most active since July 1973. The disturbance became **Ken-Lola (13W-14W)** and took an elongated cycloidal track, passing close to Okinawa before making landfall on the coast of eastern China. While in warning status, JTWC considered the system as two separate tropical cyclones. A detailed post-analysis, even though not absolutely conclusive, strongly suggested that Tropical Storms Ken (13W) and Lola (14W) were most probably the same system. Tropical Storm Ken-Lola (13W-14W) underscored the limitations of remote sensing for locating some poorly organized systems. Synoptic data proved invaluable in identifying and classifying the system while in warning status and in post-analysis. A much larger mid-level cyclone in which the tropical cyclone was embedded appeared to be the major influence on Ken-

Lola's (13W-14W) track.

AUGUST

As the most active July since 1973 came to a close, Typhoon Judy (11W) was dissipating over Korea and Tropical Storm Ken-Lola (13W-14W) was threatening Okinawa. During this time, **Mac (15W)** developed northeast of Saipan in an extremely active monsoon trough that extended as far east as Wake Island. Typhoon Mac (15W) also developed at a higher than normal latitude. In addition, its track and intensity were influenced by a complex mid-latitude synoptic regime and complicated by a multi-storm environment. The typhoon had a general northwest track, interrupted by 48 hours of westward movement before it resumed an accelerated north orientated track, and made landfall east of Tokyo. Mac (15W) weakened rapidly as it moved into and across the Sea of Japan and dissipated over southern Sakhalin Island. Soon thereafter, Typhoon **Owen (16W)** slowly spun up in the monsoon trough while moving on a general northwestward to northward track. Due to the proximity of **Nancy (17W)**, which developed at the extreme eastern end of the monsoon trough and was intensifying to the east, Owen (16W) took more than a week to reach tropical storm intensity. Later, Owen's (16W) three days of binary interaction with Typhoon Nancy (17W) resulted in an unusual southeasterly track during its developing stage. Then, the tropical cyclone followed Nancy (17W) through recurvature, extratropical transition and into high latitudes. The third tropical cyclone to develop in the monsoon trough, was **Peggy (18W)**. After a brief interaction with Owen (16W), Peggy (18W) was short-lived and only reached minimal tropical storm intensity. Then came **Tropical Depression 19W** with its unusual curved track to the north, west, and then south which appeared to coincide with the overall motion displayed by a larger, mid-level low. As the mid-level low began to fill, the tropical depression escaped its influence, and the track of the cyclone straightened out, moving westward within the easterly steering flow.

Forming just north of Taiwan, **Roger (20W)** moved south-eastward into the southern Ryukyu's, abruptly turned northeastward, and made landfall on Honshu. At the start, the forecast problem for this tropical cyclone was exacerbated by the difficulty in locating the system's complex center during its formative stages and the immediate threat it posed to DOD assets on Okinawa. The eighth and final tropical cyclone of August, **Tropical Depression 21W**, developed on the eastern end of the monsoon trough which was located to the northeast of the Mariana Islands. Because JTWC recognized that intensification would be inhibited by strong vertical wind shear, only Tropical Depression Warnings were issued.

SEPTEMBER

The first of the September tropical cyclones, **Sarah (22W)** proved to be a bona fide challenge to forecasters. The cyclone apparently underwent a binary interaction with a secondary low east of Luzon and later, when it stalled east of Luzon, was involved with the development of a sympathetic low on the lee side of Luzon. From genesis involving two distinct cloud masses to accelerating toward the Philippines, stalling just east of Luzon, moving north and rapidly reintensifying, then looping over eastern Taiwan, Sarah (22W) was one of the most difficult storms of the year to forecast. Sarah (22W) finally moved northwestward across northern Taiwan and dissipated in China. Generating in early September at the eastern end of the monsoon trough, **Tip (23W)** executed an unusual track to the northeast, then recurved after moving northwestward around the subtropical ridge, and finally tracked eastward with the polar westerlies. Tropical Storm Tip (23W) reached its peak intensity at 37° north latitude, two days after recurvature. Developing in the monsoon trough north of Guam, Tropical Storm **Vera (24W)**, after some initial erratic motion, moved on a west-northwestward track, threatened Okinawa, and made a devastating landfall just south of Shanghai. About 24 hours after Tropical Storm Vera (24W) had dissipated over eastern China,

the first warning on **Wayne (25W)** was issued. The last of four tropical cyclones to mature in September, Typhoon Wayne (25W) was also the last tropical cyclone of 1989 to affect Japan. It was unique in that it intensified after recurvature, partly as a result of its rapid acceleration. Wayne (25W) caused considerable destruction, mudslides and some deaths in Japan.

OCTOBER

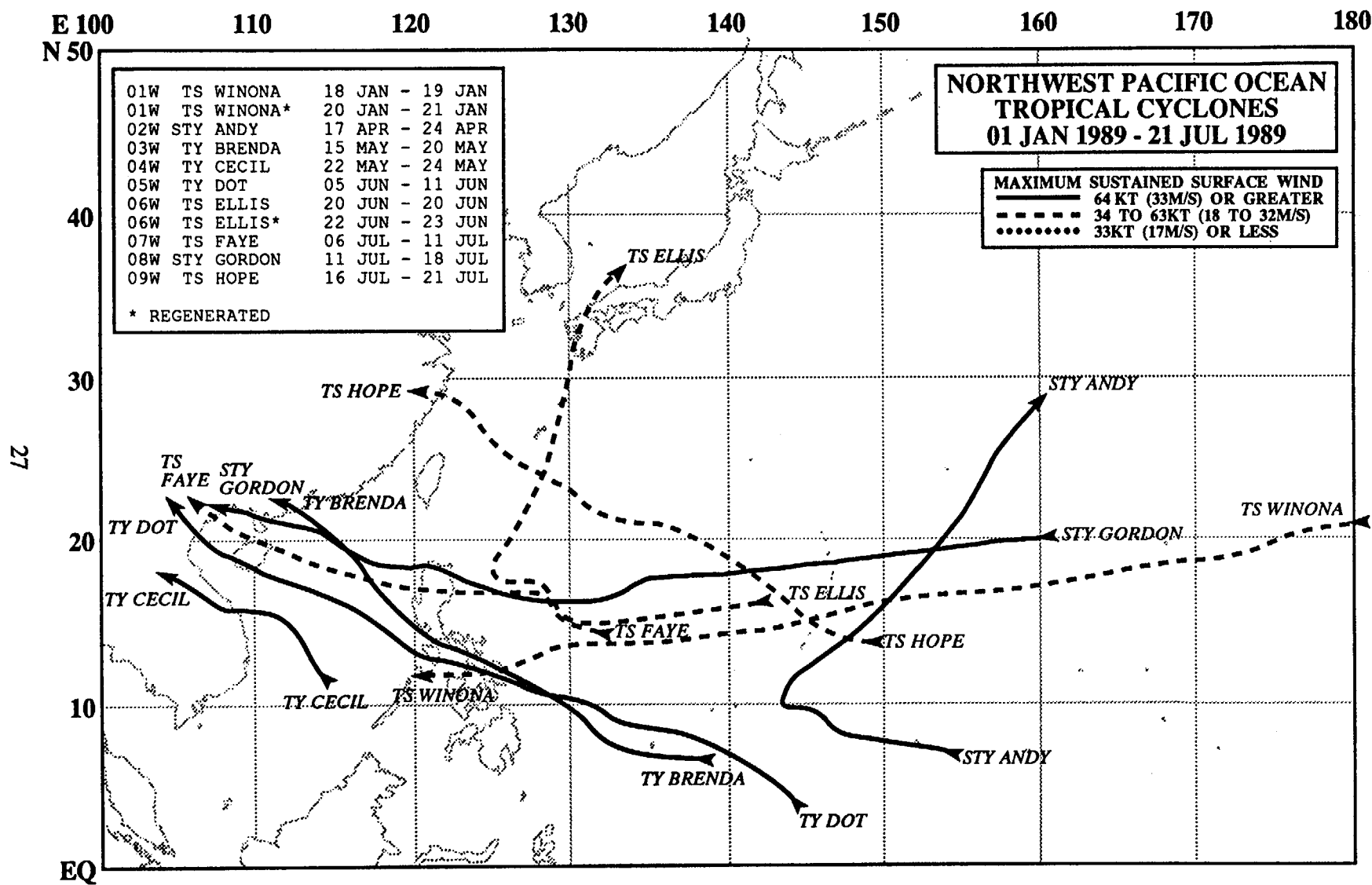
During late September, the monsoon trough, located near 10° north latitude, became very active after a week of little convective activity. The first tropical cyclone of a three-cyclone outbreak in the monsoon trough during a three-day period, **Angela (26W)** had the unique distinction of being in warning status longer than any other tropical cyclone in the western North Pacific this year — 12 days. JTWC issued a total of 46 warnings on this typhoon. Angela (26W) was also one of five tropical cyclones to reach super typhoon intensity in 1989. Developing south of Guam, Angela (26W) tracked slowly westward and struck northern Luzon with super typhoon intensity causing a large number of casualties and widespread destruction. It then continued into the South China Sea, where it reintensified, and finally made landfall in central Vietnam. As Angela (26W) developed over the Philippine Sea, the monsoon trough became active across the South China Sea from western Luzon to Vietnam and spawned typhoon **Brian (27W)**. Typhoon Cecil (04W) in May and Brian (27W) in late September and early October were the only tropical cyclones of the year to develop and spend their entire lifetimes within the confines of the South China Sea. Nearly 4000 nm (7400 km) to the east, a deep trough penetrated into the tropical western North Pacific near the dateline and **Colleen (28W)** formed at the base of the trough. Colleen (28W) passed through the northern Mariana Islands before recurving south of Japan. The tropical cyclone maintained

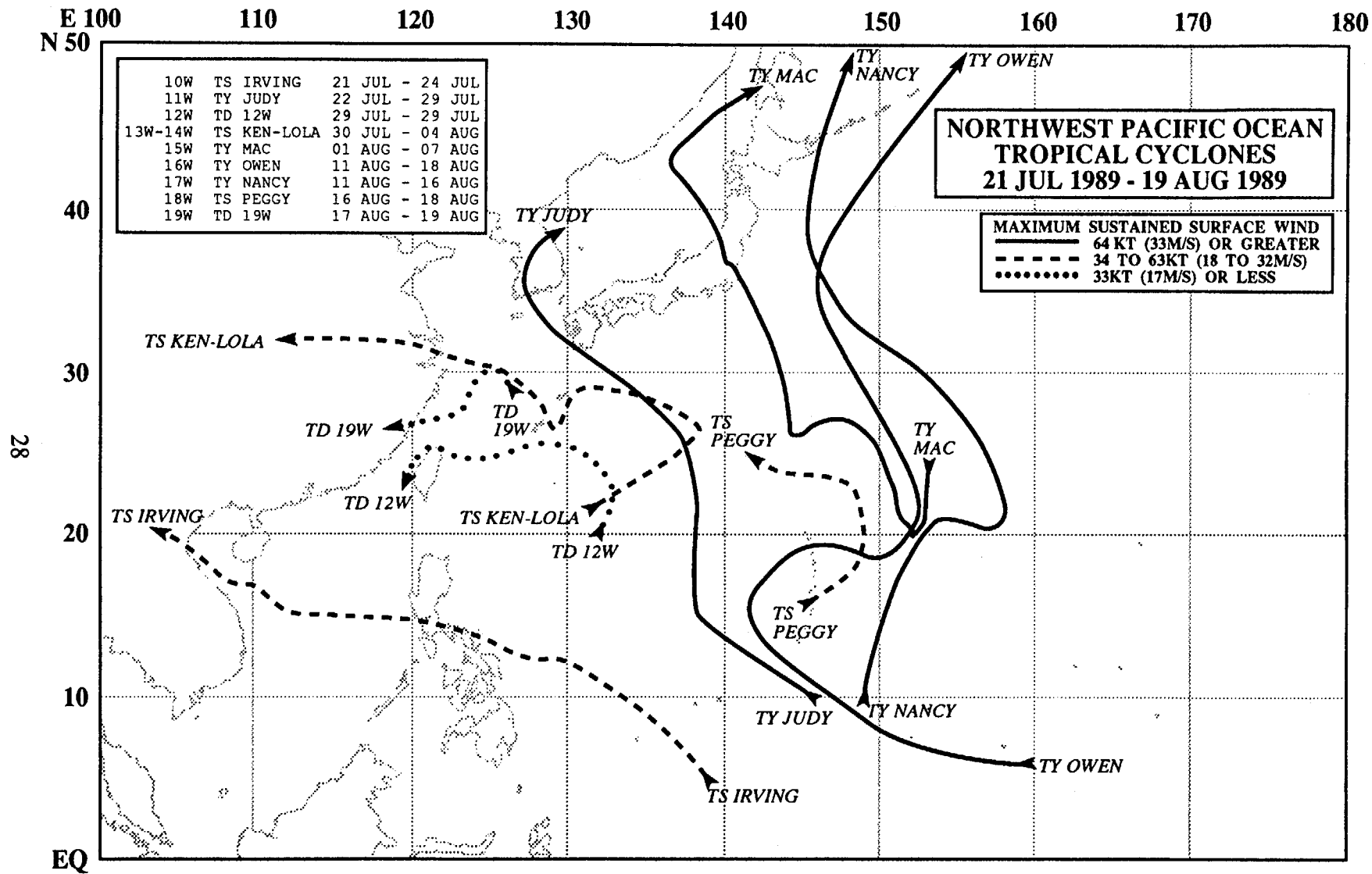
typhoon intensity until it completed extratropical transition, threatening PACEX 89 — the largest US Navy exercise conducted in the Pacific since the Korean War. Colleen (28W) highlighted the difficulty of tracking poorly organized systems with only nighttime infrared satellite imagery, but also showed the value of data from the microwave imager as a tool to help locate these systems. Forming from a disturbance in the monsoon trough near Truk in the central Caroline Islands, **Dan (29W)** followed a steady west-northwestward track and crossed the central Philippine Islands. Coming just days after Typhoon Angela's (26W) destructive passage across northern Luzon, Dan (29W) added to the misery heaped on the Philippines by its predecessor. The cyclone reintensified in the South China Sea and made landfall on the coast of central Vietnam where it caused more destruction. In the wake of Super Typhoon Angela (26W) and Typhoon Dan (29W), Super Typhoon **Elsie (30W)** became the third tropical cyclone to hit the Philippine Islands within 12 days. Elsie (30W) developed from a TUTT-induced wave in the easterlies and tracked westward throughout its life. In the Philippine Sea, Elsie (30W) rapidly intensified and struck central Luzon with an intensity of 140 kt (72 m/sec). It was cited as the most intense cyclone to strike the Philippine Islands this year. Because of its small size, Elsie (30W) weakened dramatically as it moved across the Philippines, and did not reintensify as it traversed the South China Sea. The cyclone dissipated after making landfall in central Vietnam. The last of six tropical cyclones in October and the 17th cyclone of at least typhoon intensity for the year, **Forrest (31W)** was slow and erratic in its development. Throughout its early life, Forrest (31W) was a sloppy, broad system. After passing Guam, Forrest (31W) finally intensified and ultimately became a respectable 95-kt (49-m/sec) typhoon. Soon thereafter, it recurved and accelerated rapidly to the northeast becoming one of the year's strongest extratropical cyclones.

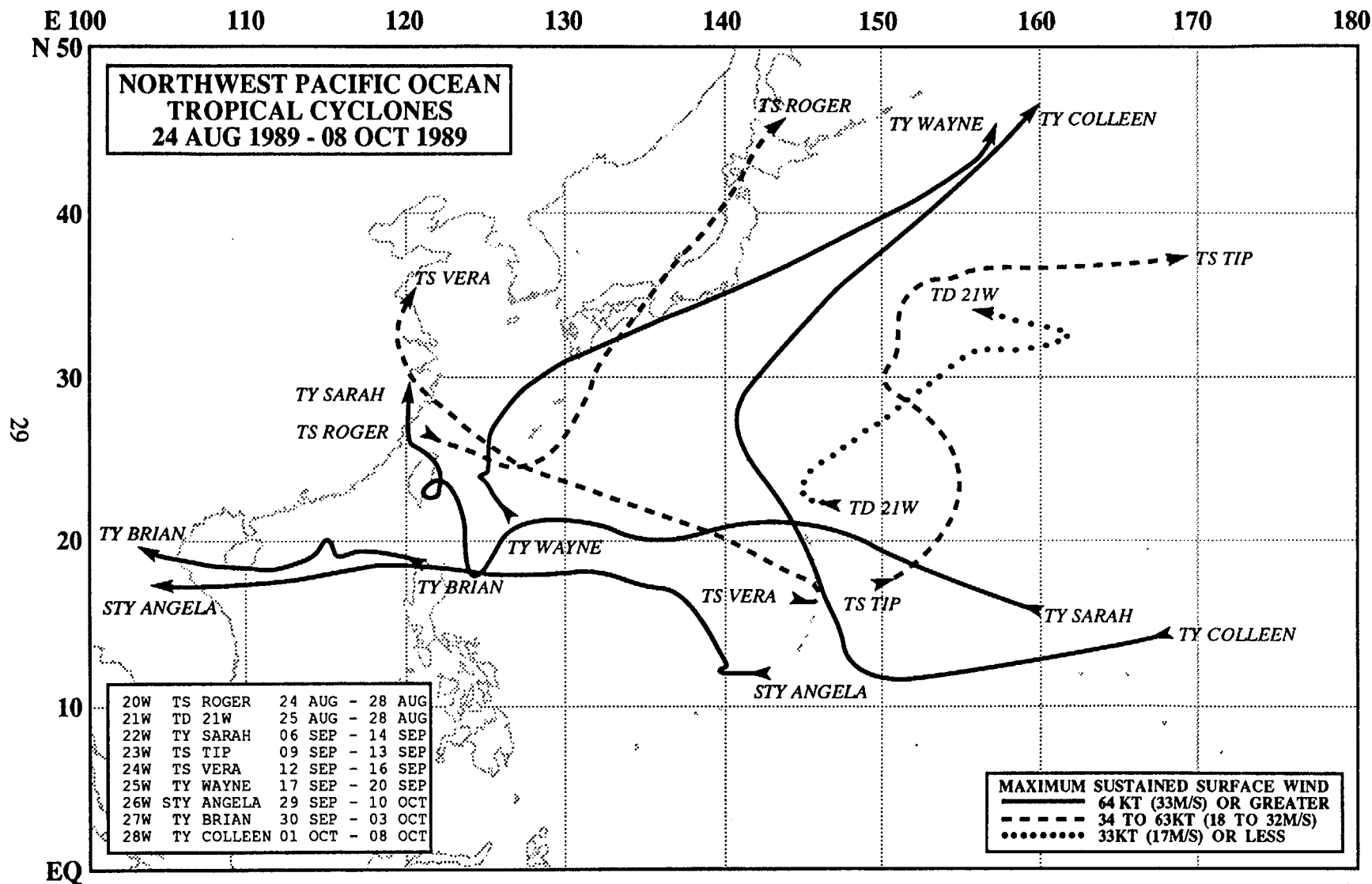
NOVEMBER THROUGH DECEMBER

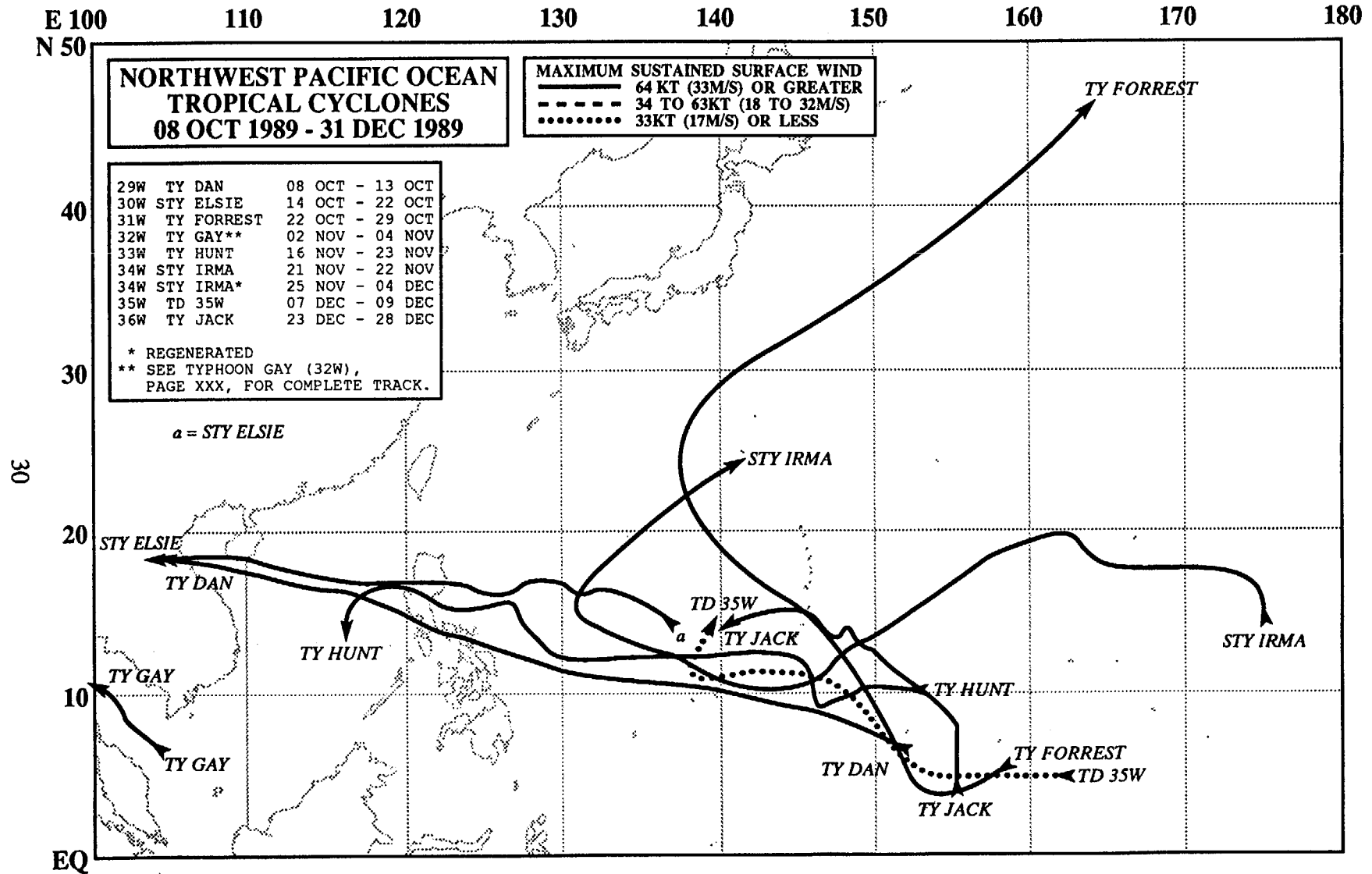
The first tropical cyclone of November turned out to be the worst tropical cyclone to affect the Malay Peninsula in 35 years. **Gay (32W)** generated in the Gulf of Thailand, sank numerous ships, crossed the Malay Peninsula into the Bay of Bengal and slammed into India with peak sustained winds of 140 kt (70 m/sec). Unique because of its small size, great intensity, and point of origin, Gay (32W) challenged forecasters by crossing two different tropical cyclone basins and almost entering a third. Except for Typhoon Gay (32W), early November was relatively inactive in the western North Pacific. In mid-November, **Hunt (33W)** initially appeared as a weak tropical disturbance in the monsoon trough. Hunt (33W) was the fourth typhoon, following **Angela (26W)**, **Dan (29W)** and **Elsie (30W)**, to strike the Philippine Islands within six weeks. Generally a westward moving system, Hunt (33W) was slow to develop, but intensified rapidly in the western Philippine Sea. As it approached the Philippines, the cyclone underwent a "stair step" before resuming a westward course into central Luzon. Unlike its predecessors, Hunt (33W) dissipated in the South China Sea after crossing Luzon. **Irma (34W)** was the third and final tropical cyclone to form in November. It's

development and track were dictated by complex mid-latitude and monsoonal regimes. Initially, Irma (34W) was slow to develop, however, rapid intensification followed once it entered in the Philippine Sea. Irma (34W) lasted 17 days and required a total of 39 warnings — only Super Typhoon **Angela (26W)** exceeded this longevity with its 46 warnings. As Super Typhoon Irma (34W) weakened in the Philippine Sea, **Tropical Depression 35W** was detected on the first day of December in the western Marshall Islands. The depression lasted more than a week as a discrete system, although it was in warning status only 48 hours. The second tropical cyclone to form in December, **Jack (36W)** was the twenty-first tropical cyclone of the year to attain at least typhoon intensity, and was the final tropical cyclone of the year. Typhoon Jack (36W) was noteworthy for the unusually long period it remained stationary. Not surprisingly, the unusual motion of Typhoon Jack (36W) was accompanied by an equally unusual intensification and dissipation pattern. The cyclone rapidly intensified from 30 to 125 kt (15 to 64 m/sec) in three and a half days, then fell apart completely. In this remarkable dissipation, Jack's (36W) maximum winds dropped from 105 to 30 kt (54 to 15 m/sec) in 24 hours.

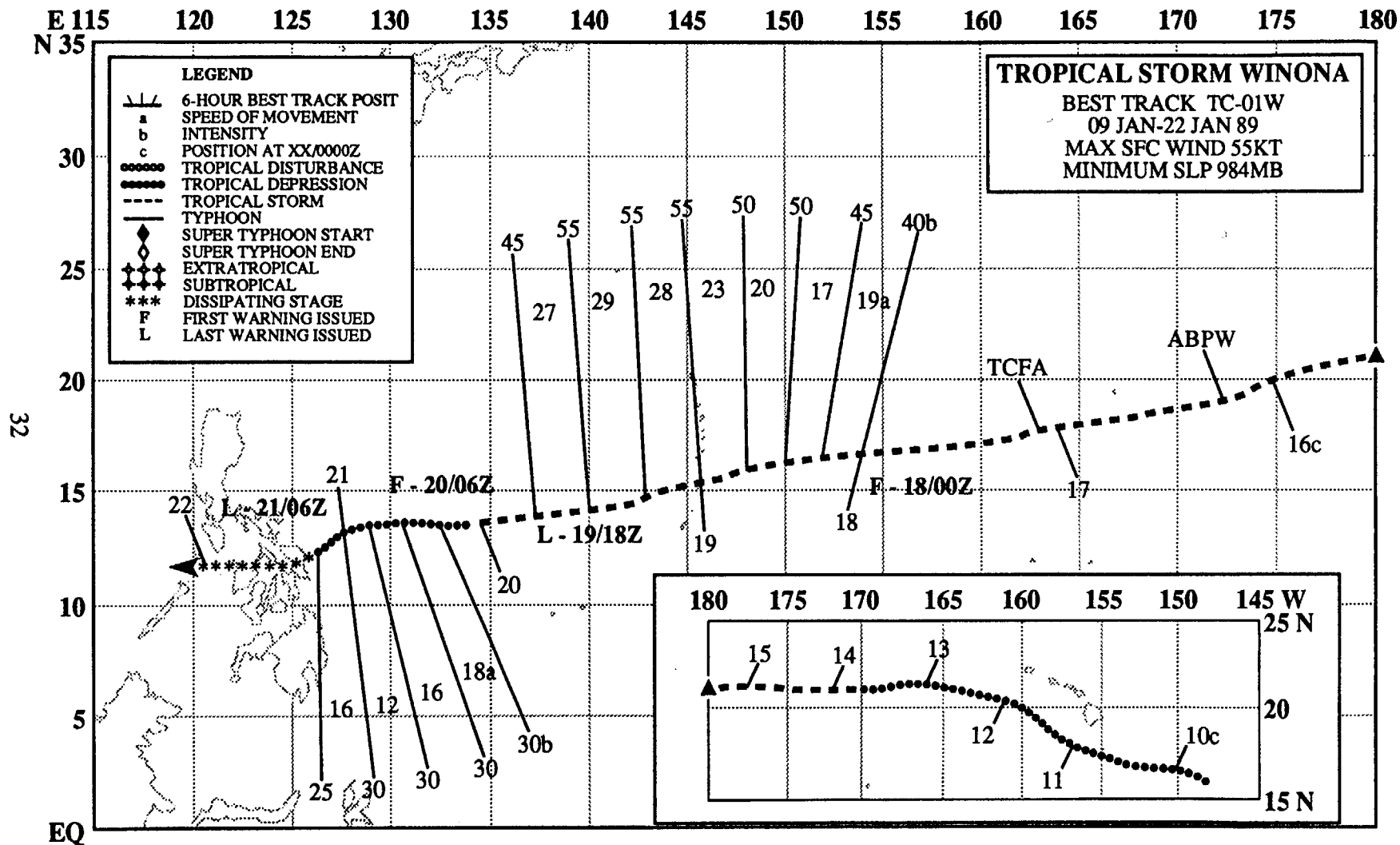








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TROPICAL STORM WINONA (01W)

The first western North Pacific tropical cyclone of 1989, Winona quietly began in the eastern North Pacific southeast of the Hawaiian Islands. The system was unusual because of its compact size and persistence. In two weeks it traveled over 5500 nm (10,185 km) before finally dissipating in the Philippine Islands.

At the start of the second week of January, 40-kt (21-m/sec) upper-level westerly winds funneled through a trough located just east of the Hawaiian Islands and created a broad area of divergence aloft to the southeast. In response, an area of deep convection persisted under the divergence and over the east-southeasterly winter trades. As the upper-level trough relocated eastward at 091200Z, a swirl of low-level cloudiness (Figure 3-01-1) became exposed, leaving behind its convective cloudiness, and moved to the west-northwest as a wave until 11 January. Then the supporting convection flared up (Figure 3-01-2), triggering flash floods on Kauai. As the system assumed a

more westward track on 12 January, it again passed under another upper-level trough. This time, however, the central convection persisted. Sparse surface data indicated a small area of light westerly winds to the south of the circulation center and a minimum sea-level pressure center of 1010 mb.

On 16 January, the compact system still retained its deep convection. It had traversed the Central Pacific in the dead of winter at 20° north latitude and persisted, which is extremely unusual. In fact, Winona was so unique that the analog and climatological forecast guidance was not available, or very limited, for most of the tropical cyclone's lifetime. It had crossed the international dateline the day before and was now approaching Wake Island. At 160600Z, the Significant Tropical Weather Advisory mentioned its persistent circulation and central convection. Later, at 161800Z, it was 75 nm (140 km) south of Wake Island (WMO 91245),

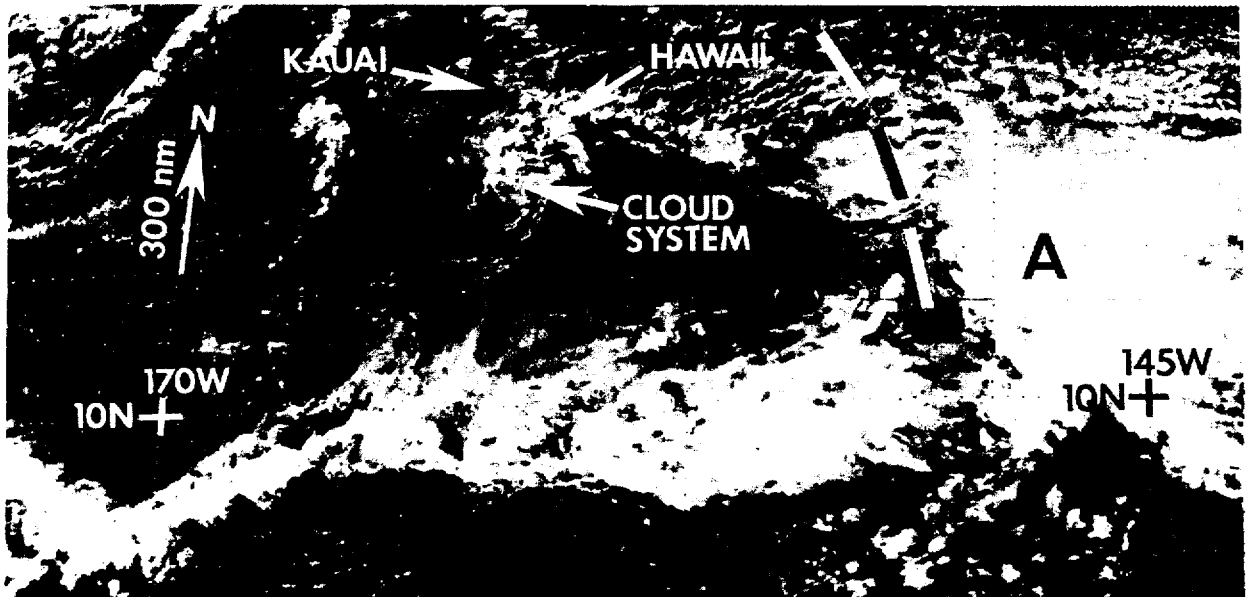


Figure 3-01-1. The low-level cloud system is passing south of the island of Hawaii. The area of bright cloudiness near point A is located east of the upper-level trough (102316Z January GOES West visual imagery courtesy of the National Weather Service Forecast Office, Honolulu, Hawaii).

which experienced maximum sustained surface winds of 25 kt (13 m/sec) and gradient-level winds (Figure 3-01-3) of 30 kt (15 m/sec).

After Winona passed Wake Island, a satellite intensity estimate of 25 kt (13 m/sec) coupled with the system's translational speed of more than 20 kt (37 km/hr) prompted a Tropical Cyclone Formation Alert at 170030Z. The subject of the Alert was upgraded to Tropical Storm Winona at 180000Z based on persistent central convection, the satellite intensity analysis and the cyclone's rapid translational speed to the west, which would cause higher winds to the north of the circulation center. Since the tropical cyclone was embedded in broad easterly flow, a "straight runner" was forecast.

Just at the end of 18 January invaluable insight came from the ship **MV Williams** as follows, "Believe to have passed through center at 180700Z.....Barometer pressure 991 (mb) max sustained winds 045 (gusts to) 65-70 kts, combined sea-swell 35 (ft)." This ship observation resulted in a warning and final best track intensity* increase (Figure 3-01-4). Without any additional direct measurements, satellite remote sensing tracked the cold cloud tops throughout the night. First light visual satellite data and later initial radar reports from Andersen AFB, Guam (WMO 91218) found Winona south and west of the expected track (Figure 3-01-5). The tropical storm (Figure 3-01-6) with peak winds of 55 kt (28 m/sec), passed just to the north of Saipan at 190000Z. The International Airport (91232) reported

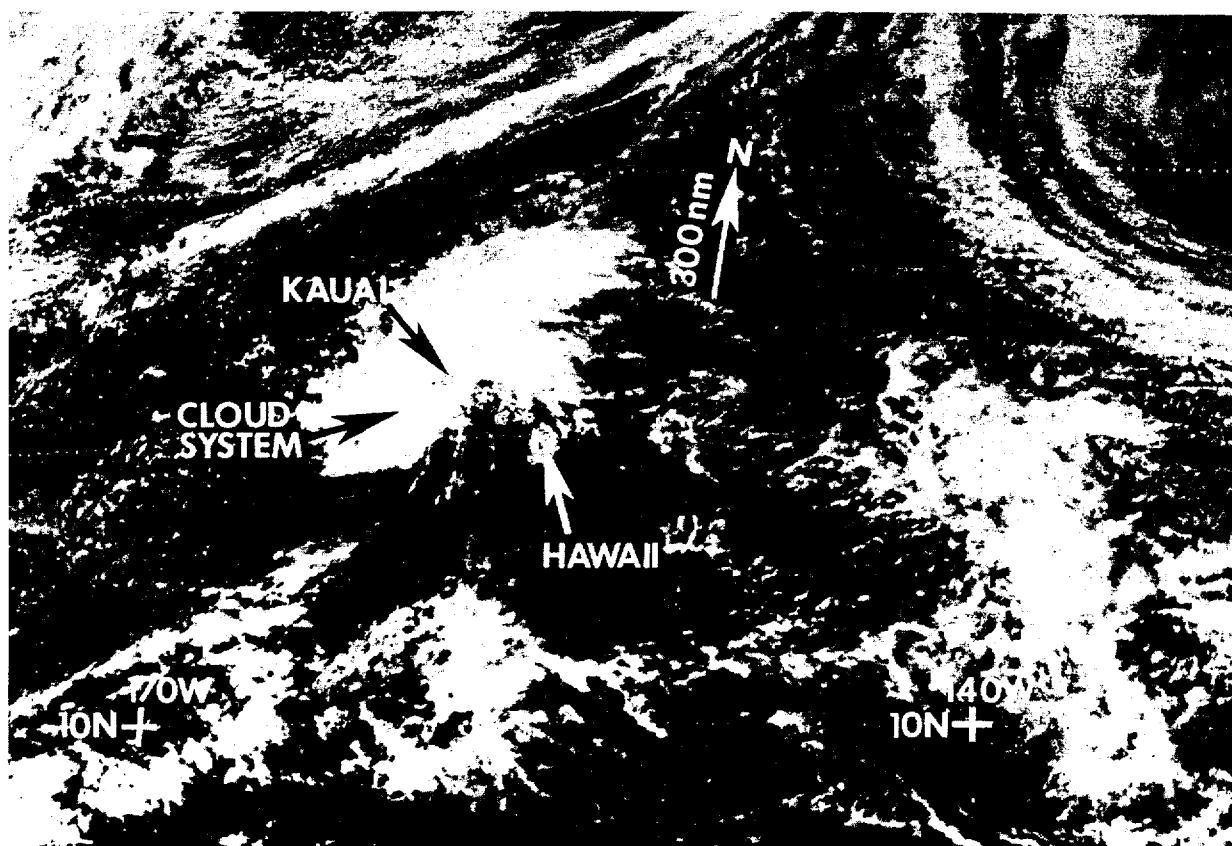


Figure 3-01-2. As the low-level vortex enters an area more favorable for development, the convection flares up (112346Z January GOES West visual imagery courtesy of the National Weather Service Forecast Office, Honolulu, Hawaii).

*This underscores a limitation of the Dvorak technique (1984), when applied to tropical cyclones that are moving along track at speeds greater than the climatic mean. Tropical cyclone forecasters should consider excess translational speed in addition to the intensity estimate, that is derived from the cloud signature, to better approximate maximum sustained surface winds.

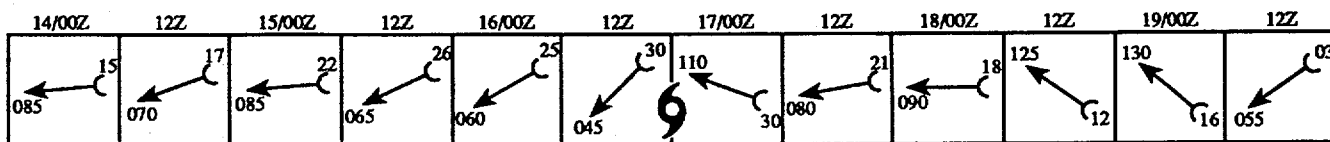


Figure 3-01-3. The gradient winds at Wake Island (91245) peak at 30 kt (15 m/sec) and undergo a directional change between 161200Z and 170000Z, as Winona passes to the south. Note the gradual speed increase from two days before Winona's passage and decrease for two days afterward.

winds of 25 kt (13 m/sec) with gusts to 35 kt (18 m/sec). No loss of life was reported Saipan.

Winona continued accelerating to the west-southwest along the southern edge of a shallow modifying polar air mass until the deep supporting convection was lost. A final warning was issued at 191800Z. However, the central convection flared up again and a regenerated warning followed at 200600Z. Just prior to landfall in the central Philippine Islands, Winona's deep central convection fell apart and the system was finalled at 210600Z.

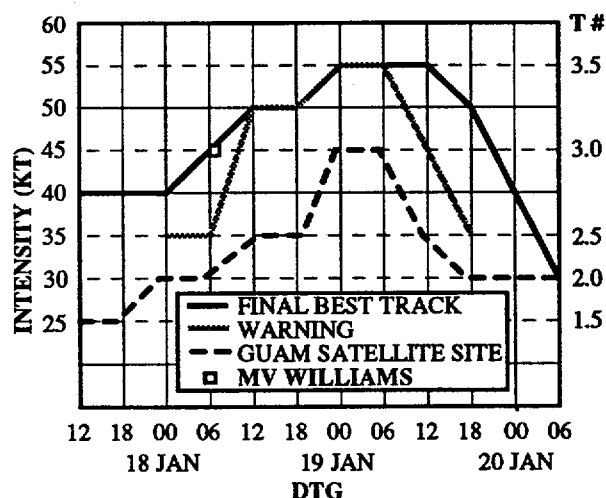


Figure 3-01-4. Impact of the ship MV Williams' 180700Z report on the warning and final best track intensities for Winona.

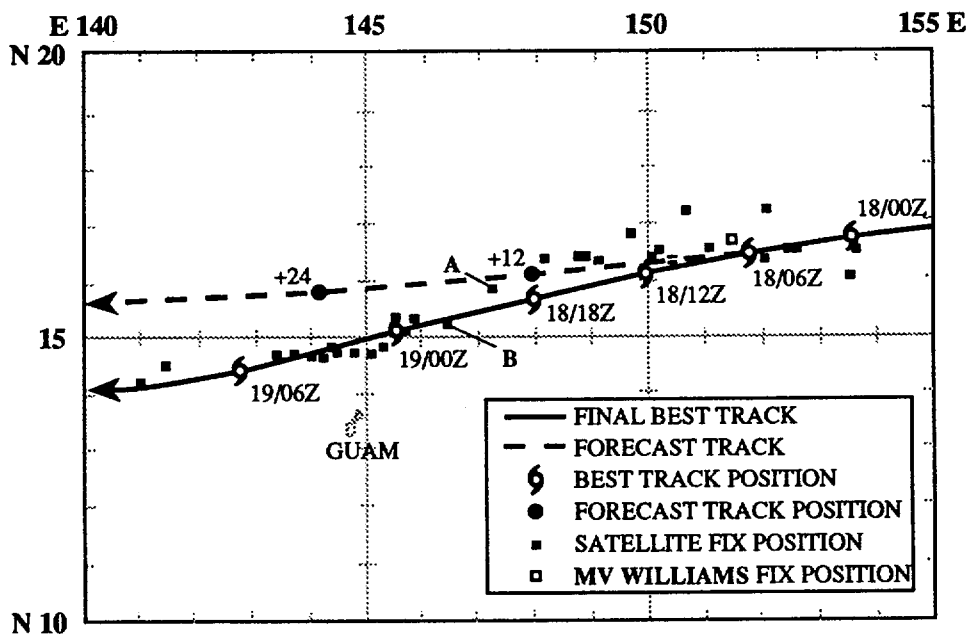


Figure 3-01-5. Comparison of expected track, raw fix data and final best track for Winona. The first daylight visual satellite fixes (A and B) were key elements in establishing Winona's continued movement to the west-southwest.

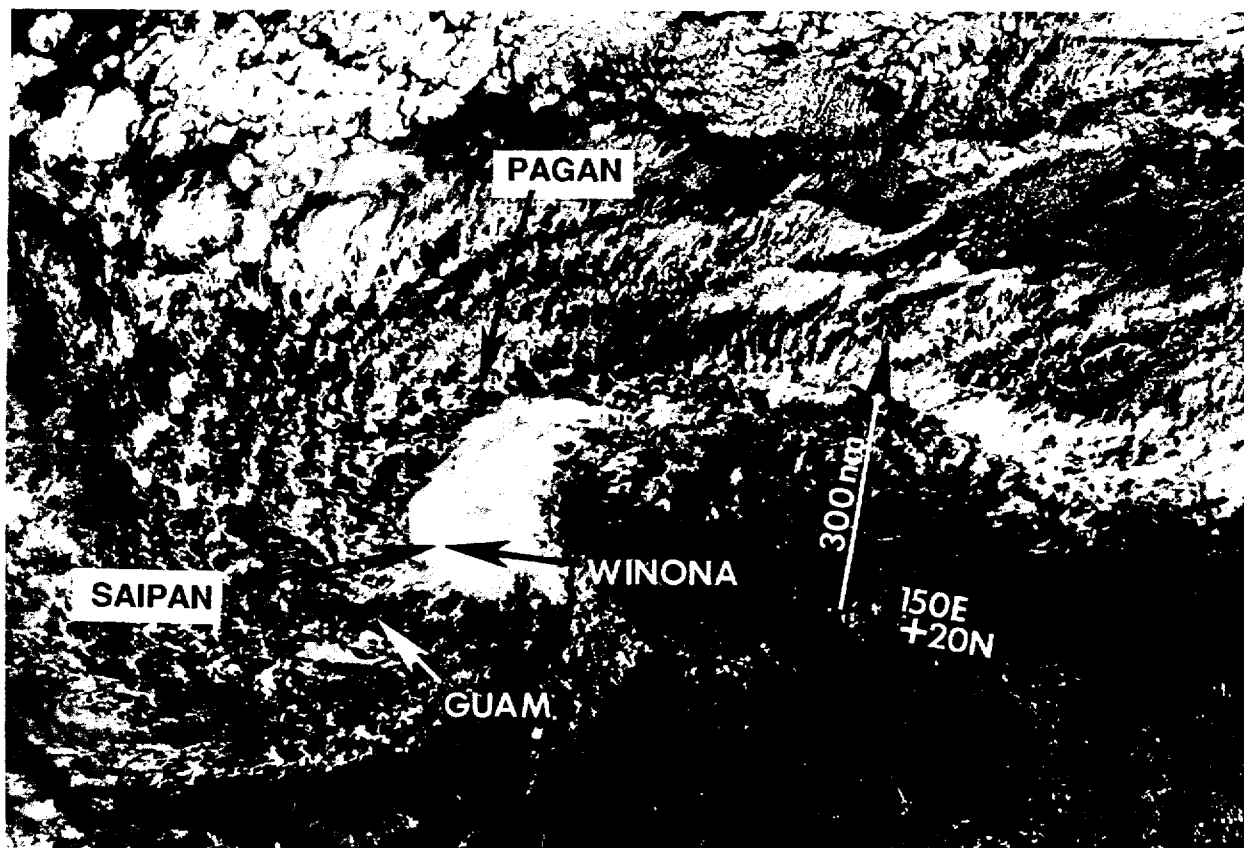


Figure 3-01-6. Tropical Storm Winona approaches Saipan. Note the compact size of the system (182321Z January DMSP visual imagery).

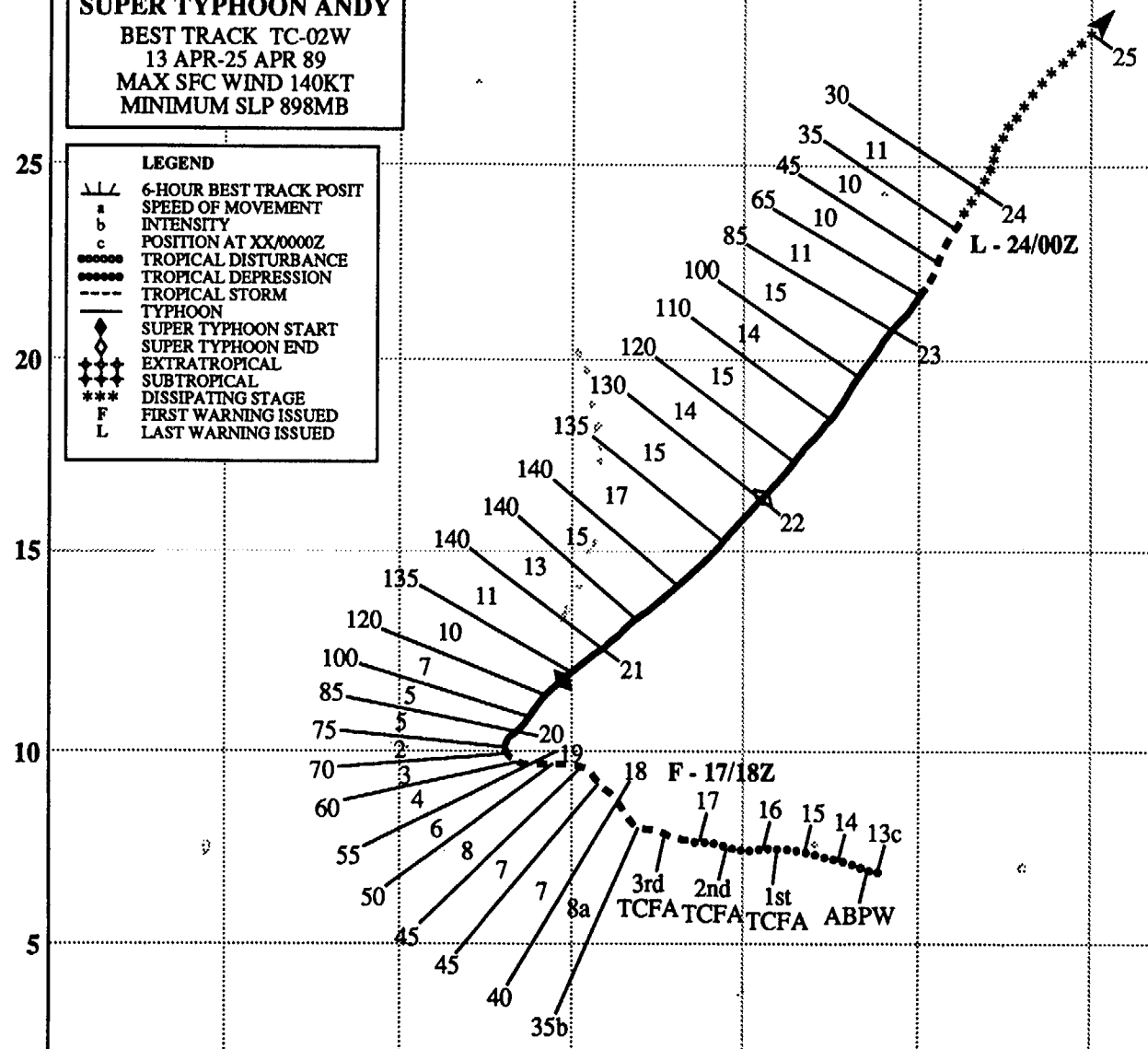
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E 130 135 140 145 150 155 160 165 170 E

N 30

SUPER TYPHOON ANDY
 BEST TRACK TC-02W
 13 APR-25 APR 89
 MAX SFC WIND 140KT
 MINIMUM SLP 898MB

LEGEND
 \ / \ 6-HOUR BEST TRACK POSIT
 a SPEED OF MOVEMENT
 b INTENSITY
 c POSITION AT XX/0000Z
 TROPICAL DISTURBANCE
 TROPICAL DEPRESSION
 - - - - TROPICAL STORM
 - - - - TYPHOON
 ◆ SUPER TYPHOON START
 ◇ SUPER TYPHOON END
 * * * * EXTRATROPICAL
 * * * * SUBTROPICAL
 *** DISSIPATING STAGE
 F FIRST WARNING ISSUED
 L LAST WARNING ISSUED



38

EQ

SUPER TYPHOON ANDY (02W)

For the western North Pacific, Andy was the second typhoon in the past nine years to form in April, the first super typhoon of 1989 and the first typhoon of the year to seriously threaten Guam.

The weather pattern the second week of April mirrored climatology with brisk, east-northeast trade winds dominating the low latitudes and only token deep convection. However, by the close of the week, the trade winds became lighter and equatorial westerlies replaced the cross-equatorial flow, or buffer, as Tropical Cyclone 26S (Orson) developed south of the equator in the Arafura Sea. North of the equator increased convection persisted near

Truk Atoll in the eastern Caroline Islands. This increased convection was first mentioned in the Significant Tropical Weather Advisory at 130600Z. Continued cloud development prompted the first Tropical Cyclone Formation Alert at 151430Z. Intensification of the system (Figure 3-02-1) was slow, however, and follow-on Alerts were issued at 161430Z and 171430Z.

As this area slowly moved westward and gradually intensified, it was finally upgraded at 171800Z to Tropical Depression 02W. Data from the Automated Meteorological Observing Station (AMOS) installed in 1988 on Faraulep Island (WMO 52005) in the central Carolines became very important as it monitored the

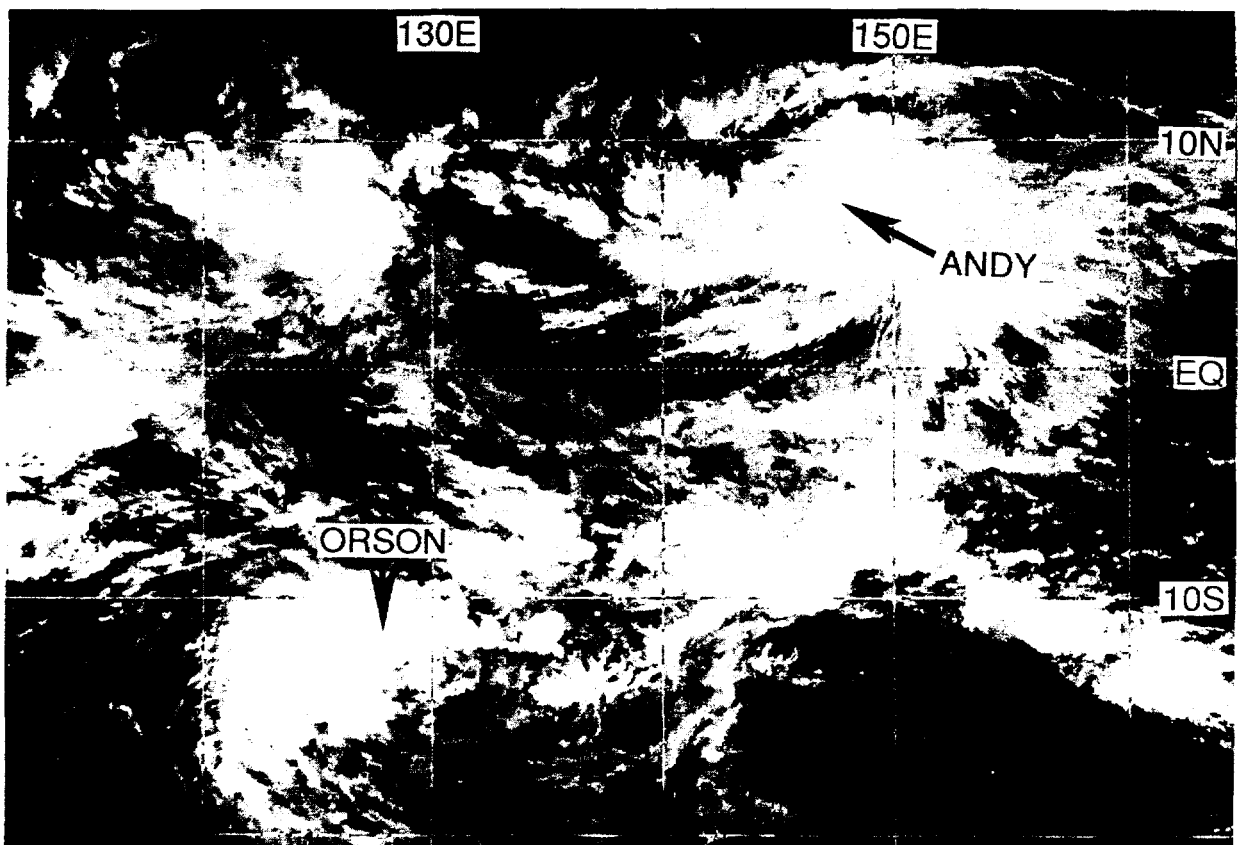


Figure 3-02-1. Satellite global data base display from the Air Force Global Weather Central captures the two tropical cyclones — Andy near Truk and Orson (26S) in the Arafura Sea (170000Z April DMSP infrared imagery).

approach of the tropical cyclone (Figure 3-02-2). In this normally data sparse area the Faraulep AMOS provided needed observations of surface pressure, wind speed and direction which provided the ground truth for the satellite data. These AMOS data (Figure 3-02-3) reflected the change of Andy's track from the west to northwest at 171800Z. After the

passage of a mid-latitude trough to the north of the system, the track returned to westward at 181200Z.

Following Andy's passage to the north of Faraulep and south of Guam, satellite fixes from 190530Z through 191730Z indicated it had ceased its westward movement and had

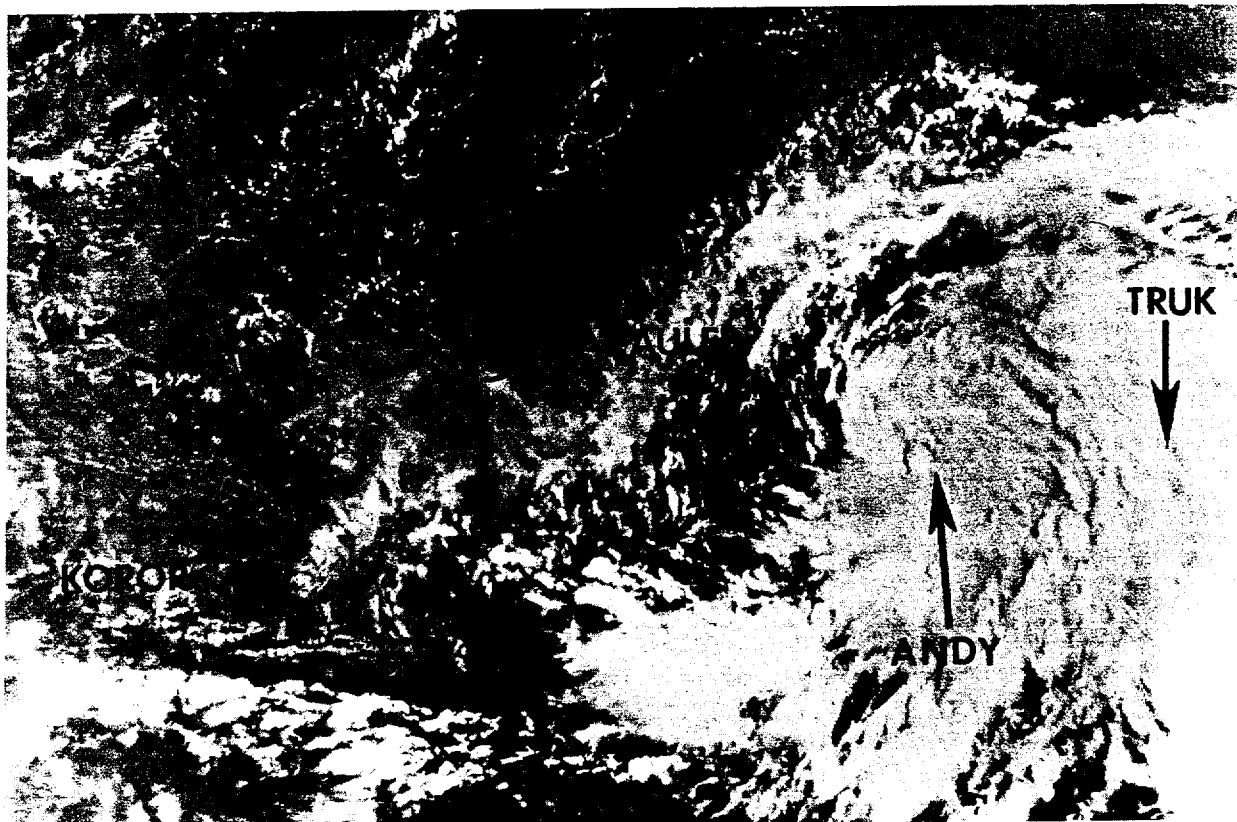


Figure 3-02-2. Andy bears down on Faraulep Island. Guam is just under the leading edge of the cirrus (172219Z April DMSP visual imagery).

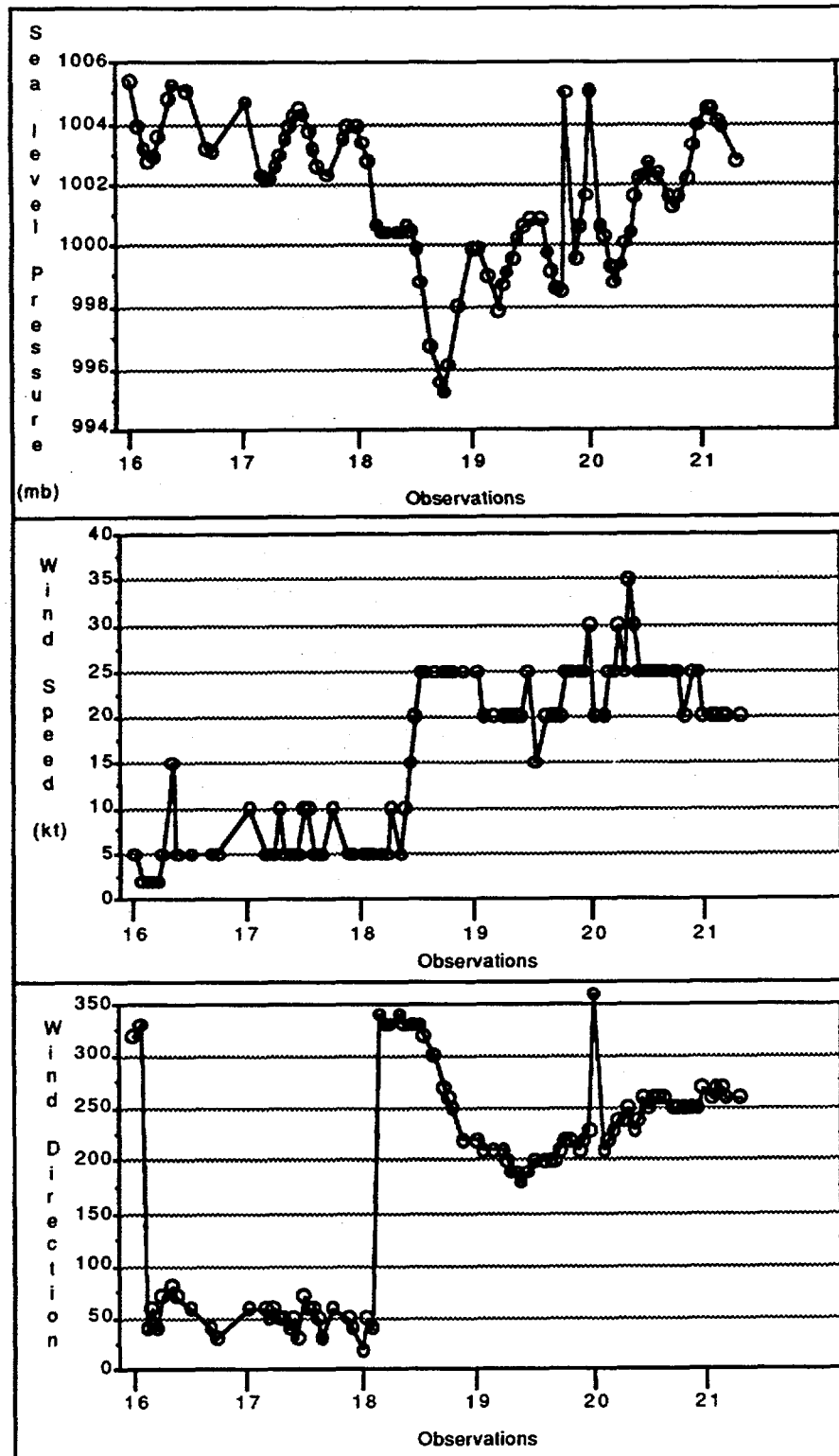


Figure 3-02-3. Faraulep AMOS reports showing: (a) time series of pressure, (b) wind speed and (c) wind direction. Andy's closest point of approach was at 181800Z. Note the major shift of wind direction and increase of wind speed preceded the lowest pressure.

begun to move to the north. Continued intensification (Figure 3-02-4) further aggravated the forecaster's dilemma. With recurvature possible as another mid-latitude trough moved eastward from Asia, there was an increasing threat to life and property in the Marianas. Until 200000Z, it appeared that the track would return to the west-northwest after a mid-latitude trough to the north progressed eastward and the lower tropospheric high pressure reestablished itself north of the

cyclone. OTCM supported this synoptic assessment (Figure 3-02-5) in contrast to the climatological techniques, primarily CLIPER, which indicated a track to the north and just to the west of Guam. But Andy's continued slow northward movement required a reassessment of the synoptic situation. The track forecast was changed from west-northwestward to north, just west of Guam, followed by recurvature. The alternate forecast scenario became an early recurvature with passage southeast of Guam.

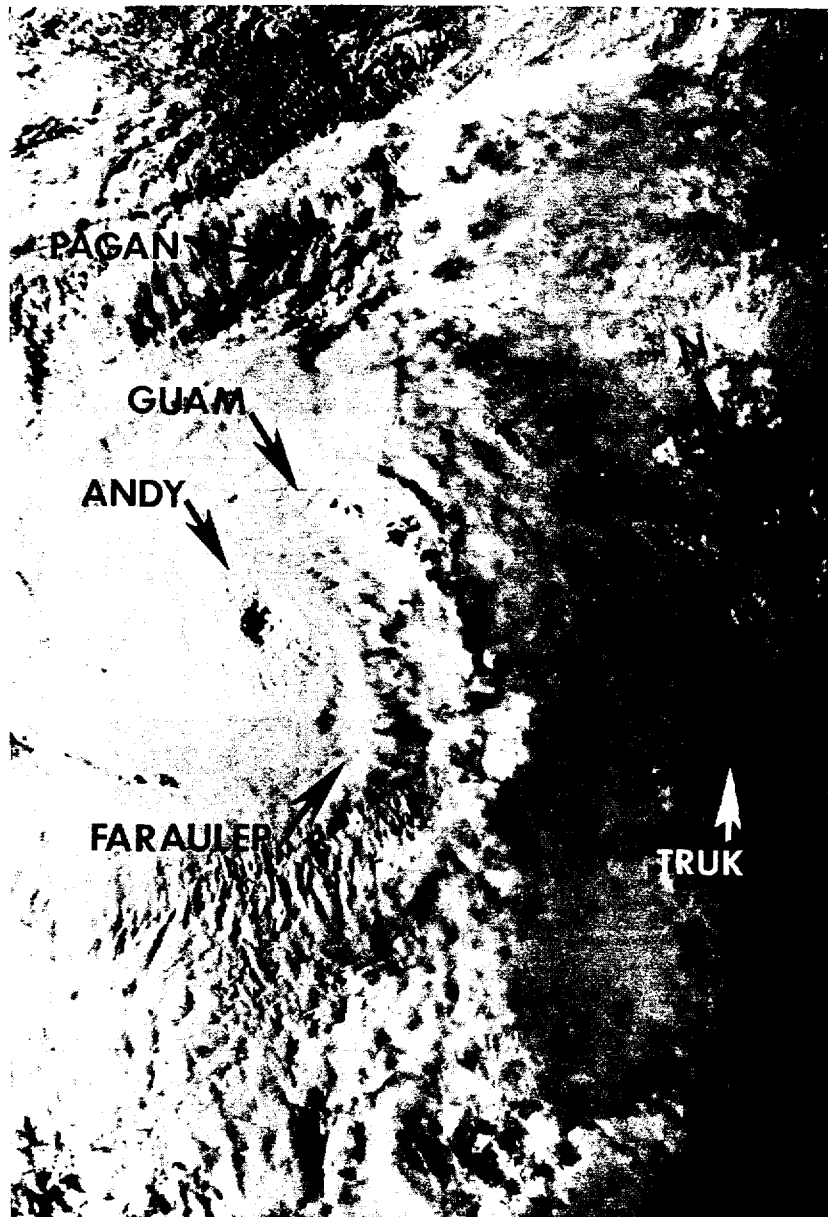


Figure 3-03-4. The low sun angle enhances the cloud top topography. Andy poses an imminent threat to the Marianas (210816Z April DMSP visual imagery).

The primary forecast held until 201700Z at which time it became apparent that recurvature had already taken place. A special tropical cyclone warning was issued with the updated forecast reflecting that Andy (Figure 3-02-6) would pass 45 nm (70 km) southeast of Guam.

Andy's closest point of approach (CPA) to Guam occurred at 202100Z 70 nm (130 km) to the southeast. The island was spared the intense maximum sustained winds near the center estimated to be 135-140 kt (69-72 m/sec). Sustained surface winds recorded on the island were 35-45 kt (18-23 m/sec) with peak gusts to 68 kt (35 m/sec). These resulted

in crop damage, power outages and minor property damage, primarily due to fallen trees. In addition, torrential downpours caused localized flooding. At sea, the combat stores ship, USS San Jose came to the aid of a disabled fishing vessel in the path of the super typhoon.

After CPA, Andy continued to track northeastward and weaken as the vertical shear from the westerly winds aloft increased. Three days later, at 240000Z, when the central convection completely separated from the dissipating low-level circulation center (Figure 3-02-7), the final warning was issued.

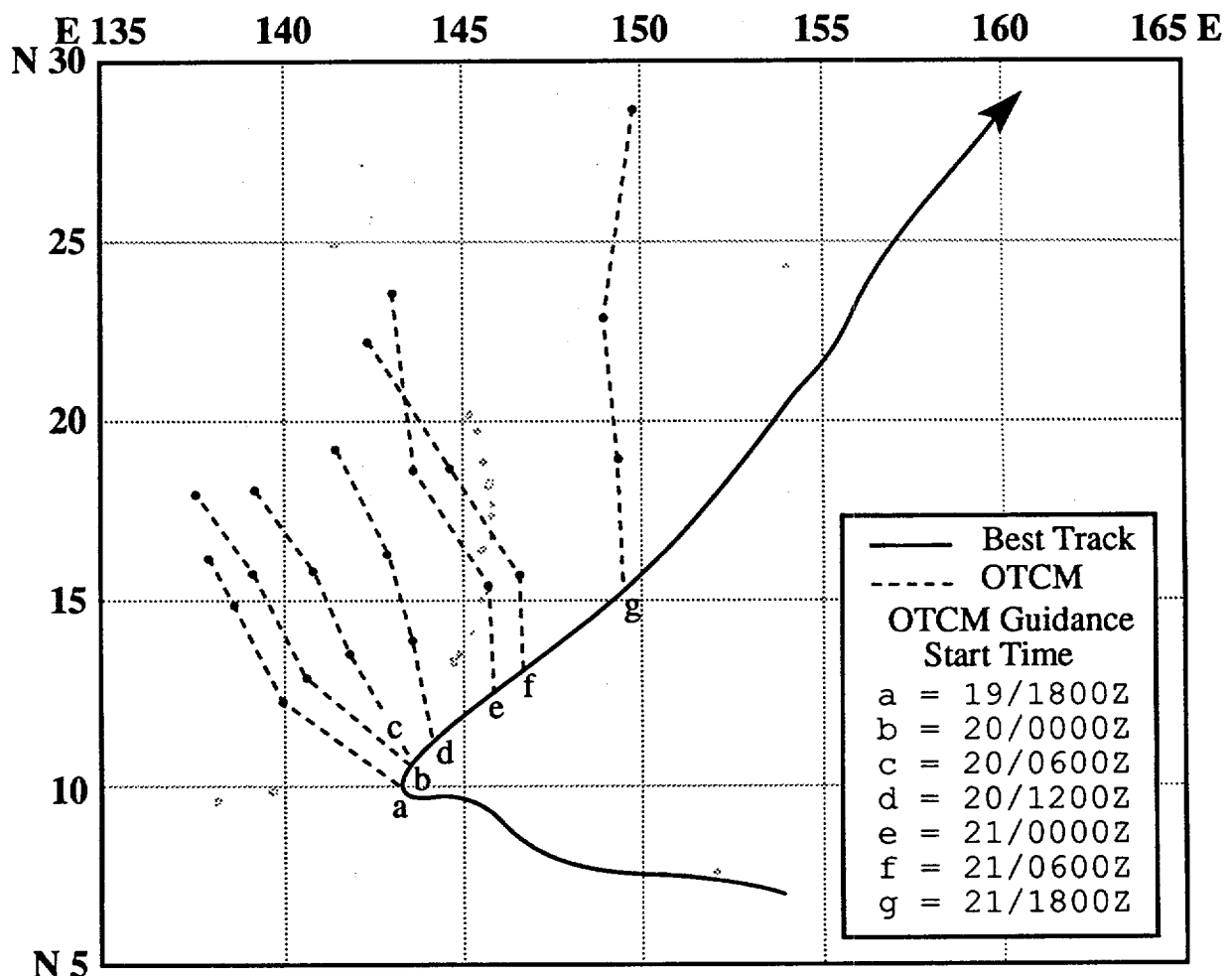


Figure 3-02-5. Comparison of OTCM guidance tracks from 191800Z through 211800Z with the final best track. After the start time for OTCM, the dots embedded in the dashed line indicate the location of the 24, 48 and 72 hour guidance.



Figure 3-02-6. Approaching super typhoon intensity, Andy is impressive on this matched pair of moonlit visual and enhanced infrared pictures (201202Z April DMSP visual and infrared imagery).

As a point of interest, Figure 3-02-8 is included to demonstrate the value of multi-spectral imaging. In the visual image the low-

level eye is completely obscured; however, a part of it can be seen in the enhanced infrared image.

Figure 3-02-7. Remnants of Andy's low-level circulation (242322Z April DMSP visual imagery).

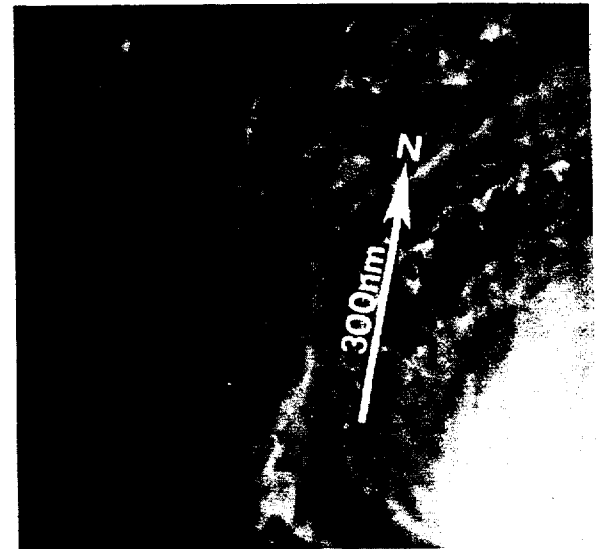
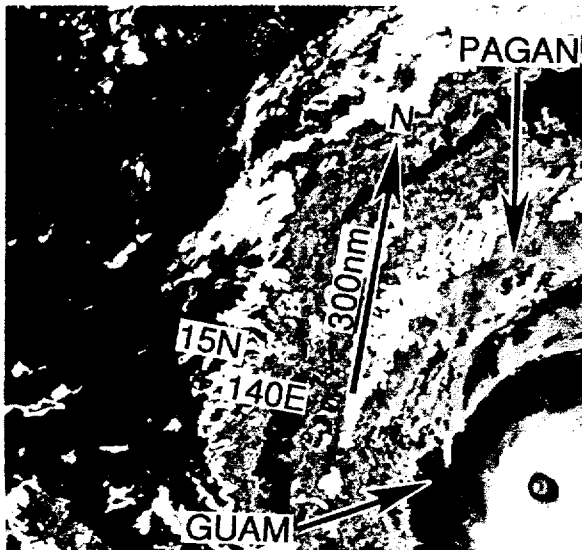
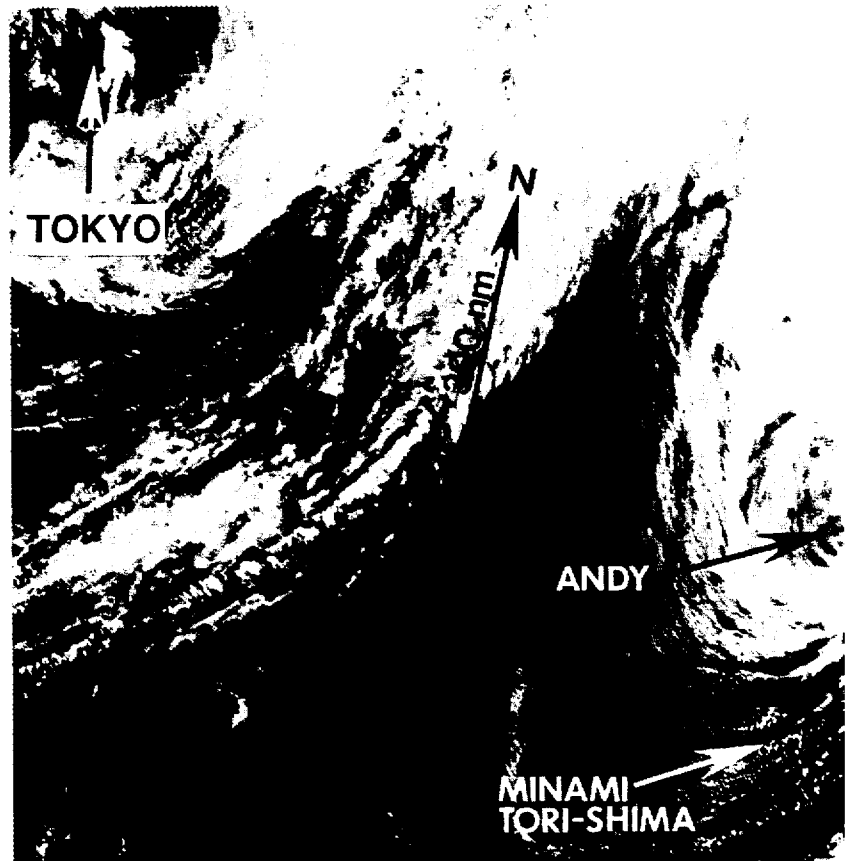
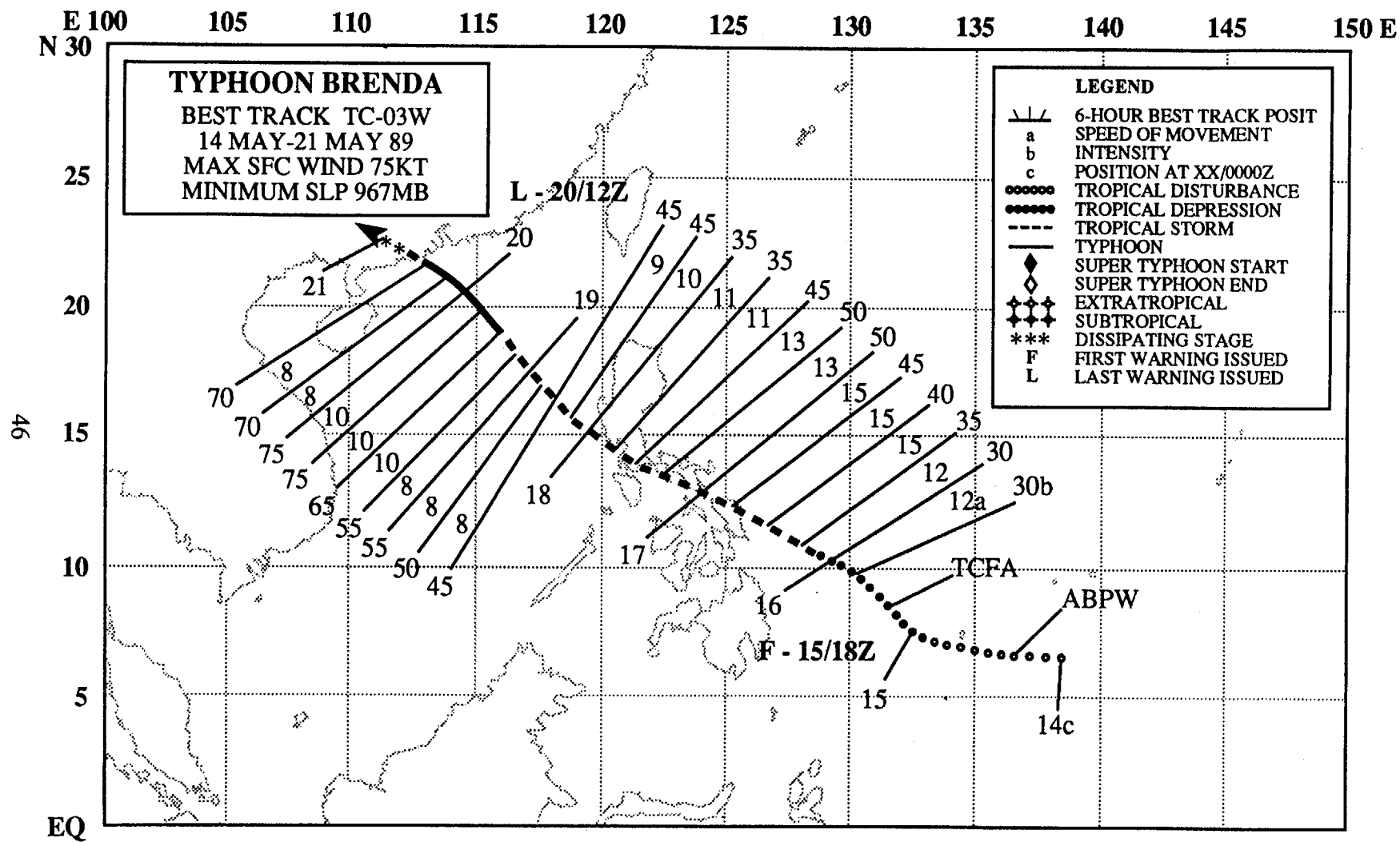


Figure 3-02-8. As Andy moves away from Guam, this picture pair shows the importance of multispectral since the eye is located at the extreme lower right edge of the polar orbiter image. Note a small portion of the low-level eye shows on the enhanced infrared (to the left). On the visual (to the right) the low-level eye is completely masked by the bright sunlight reflected from the eastern side of wall cloud (210434Z April NOAA visual and infrared imagery).



TYPHOON BRENDA (03W)

The first of two typhoons to form in May, Brenda generated in the western Caroline Islands, moved northwestward across the central Philippine Islands, and then made landfall in China. It was the second of eleven tropical cyclones to cross the Philippines during the year.

After spawning Super Typhoon Andy in April, the tropics remained relatively quiet for two weeks. Then, on 14 May, the Significant Tropical Weather Advisory mentioned an area of broad convection with weak turning in the monsoon trough south of Yap. Continued organization of clouds and winds prompted the issuance of a Tropical Cyclone Formation Alert

at 150730Z and the first warning at 151800Z. The system was upgraded to tropical storm at 160000Z.

Brenda (Figure 3-03-1) tracked across Samar and southern Luzon, exiting at the tip of the Bataan Peninsula. Closest point of approach to both NAS Cubi Point and Manila was 18 nm (35 km). Cubi Point's barograph recorded a minimum sea level pressure of 989 mb at 171800Z. To the north, Clark AB (WMO 98327) experienced maximum gusts of 38 kt (20 m/sec) and received minor damage. News reports indicated at least four water craft sank, and that more than 50 people were killed or missing in the Philippine Islands. In addition,

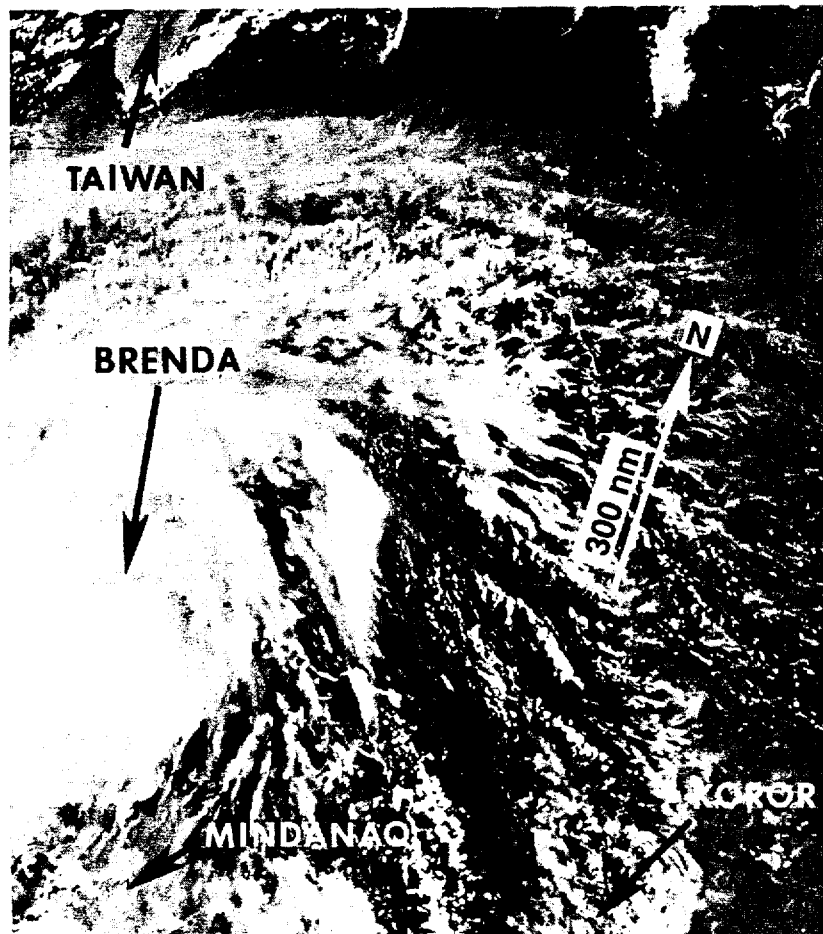


Figure 3-03-1. Brenda slams into the southern Luzon (170025Z May DMSP visual imagery).

thousands were left homeless, and communications and power were significantly disrupted.

Once in the South China Sea and again over warm water, Brenda (Figure 3-03-2) continued northwestward and intensified, reaching typhoon status at 191200Z. Meanwhile, the NOGAPs prognostic series forecast a mid-latitude short wave to move north of the tropical cyclone, indicating potential for recurvature. JTWC did forecast recurvature at 181200Z, based on an apparent

northward motion of the circulation center on the nighttime infrared satellite imagery. Low confidence radar signatures also indicated a northward motion. Subsequent fixes based on visual imagery returned the cyclone's track to a northwestward direction. In turn, JTWC returned forecasts to a northwest motion and into the coast of China, west of Hong Kong.

Typhoon Brenda reached a maximum intensity of 75 kt (39 m/sec) at 191800Z before passing within 81 nm (150 km) of Hong Kong at 201200Z. The Royal Observatory at Hong

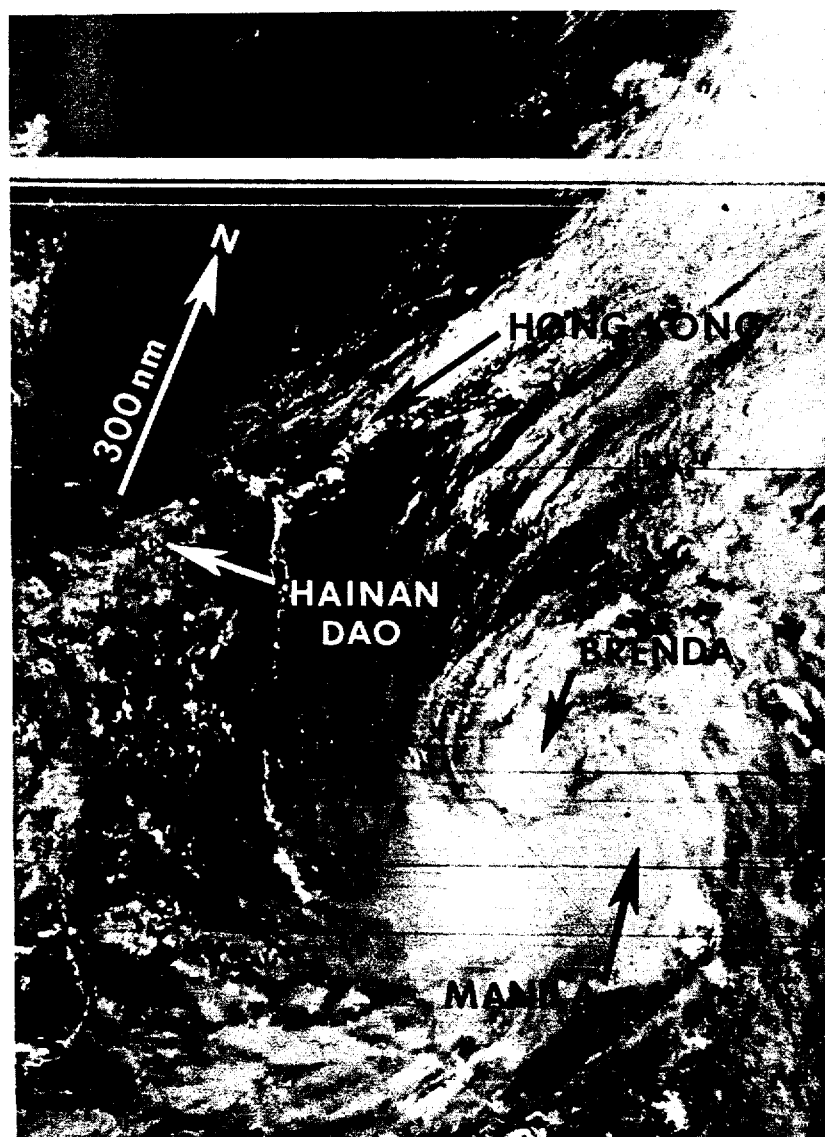


Figure 3-03-2. Moving over water, Brenda regains organization and reintensifies (180146Z May DMSP visual imagery).

Kong reported maximum gusts of 54 kt (28 m/sec), a minimum sea-level pressure of 995 mb and 17 inches (441 mm) of rain during the six days that Brenda and its enhanced southwest flow affected the area.

Brenda (Figure 3-03-3) made landfall on the south coast of China at 201400Z and dissipated over land in the Guangdong

Province. Preliminary reports indicated that at least 84 people perished in southern China, and that widespread flooding due to the heavy rains damaged about 3.5 million acres (1.4 million hectares) of land. In Hong Kong six people were killed, one was missing, and the heavy rains resulted in landslides, floods and large losses in livestock and fish farming.

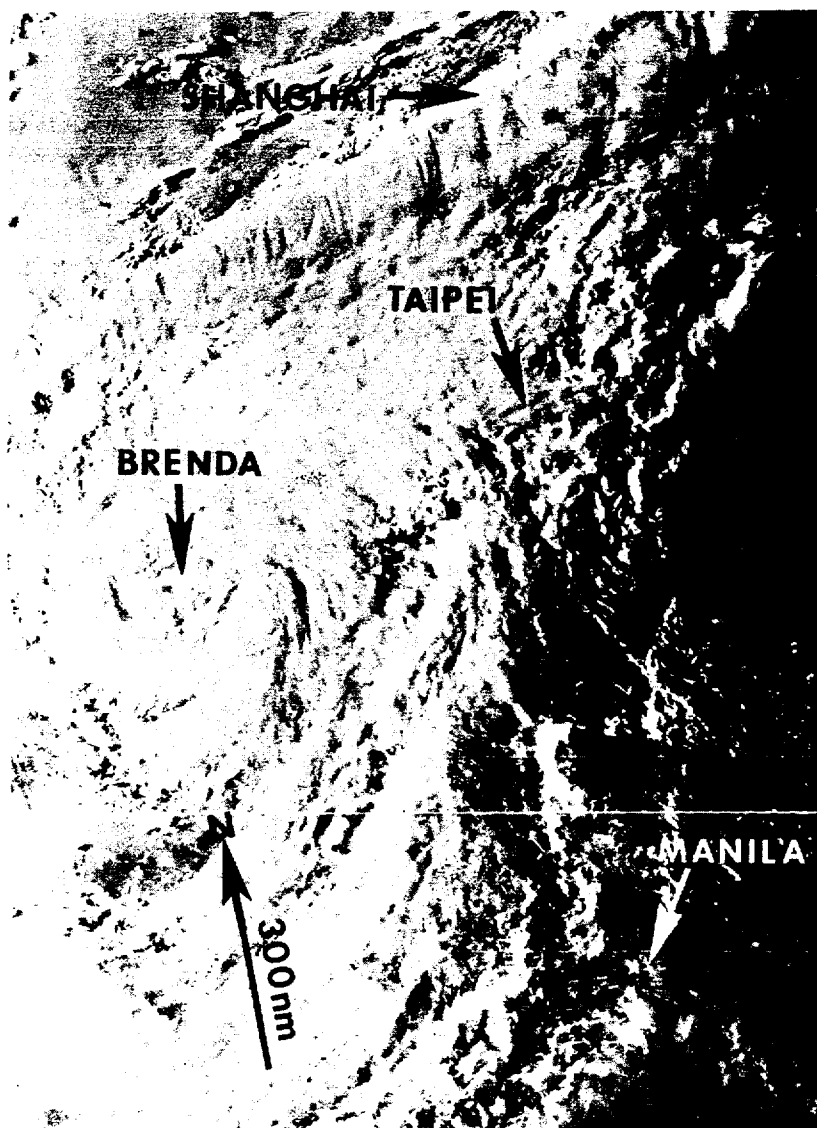
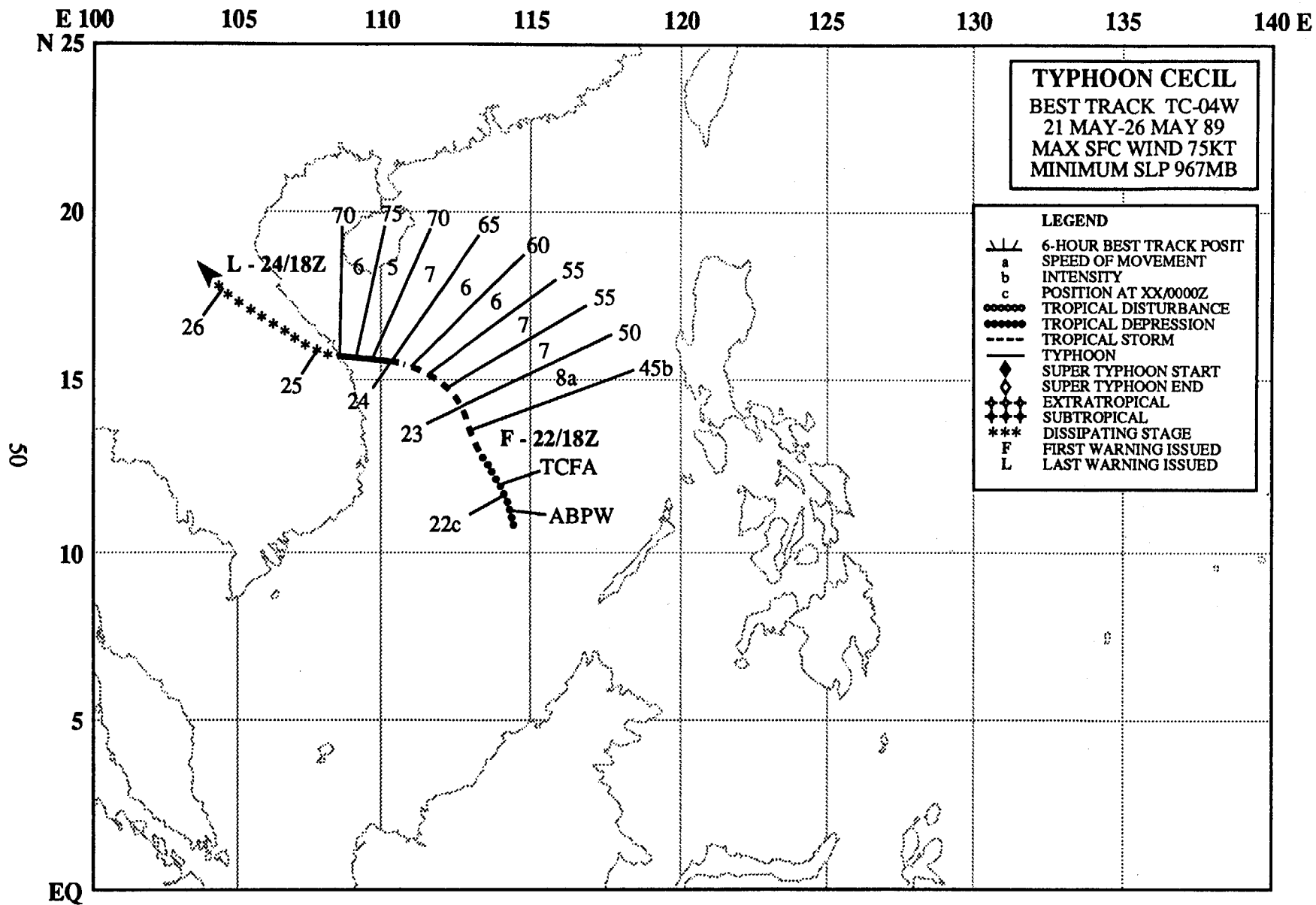


Figure 3-03-3. This brightly lit low sun angle photo shows Brenda's convective spirals as the typhoon approaches the coast. The sun is low to the west, and its rays scatter forward, through the aerosols, and out to space. The gray, milky-looking areas around the periphery of Brenda reveal the presence of aerosols in the lower layer of the atmosphere that are being trapped, and concentrated, as a result of subsidence (201021Z DMSP visual imagery).



TYPHOON CECIL (04W)

The second of two typhoons during the month of May, Cecil developed in the South China Sea in the wake of Typhoon Brenda (03W).

On 20 May, an extensive monsoon trough spread across the Bay of Bengal into the South China Sea where it terminated in Typhoon Brenda (03W). As Brenda moved northwestward and dissipated over southern China, it left behind an area of enhanced low-level southwesterly flow. Additionally, the dissipation of Brenda (03W) reduced the vertical wind shear from the north over the genesis area for Cecil. Cecil was first detected on 21 May as a low-level cyclonic circulation associated with the enhanced southwesterly flow. The Significant Tropical Weather Advisory was reissued at 212000Z to cover this circulation and its persistent cloudiness. When surface synoptic reports and additional satellite data indicated that the system was becoming better organized, a Tropical Cyclone Formation Alert was issued at 220230Z.

Initially, the deep convection was only located in the southern semicircle, but on 22 May the convection wrapped around the circulation center. This event, along with falling central pressures precipitated the first

warning on Tropical Depression 04W at 221800Z. The warning was then amended based on subsequent synoptic reports, and the system upgraded to a tropical storm.

At the start, Cecil was forecast to track northward through the weakness in the subtropical ridge created by Brenda (03W). This forecast was supported by guidance from the dynamic aid, OTCM, and HPAC, an aid which blends one half persistence with one half climatology. But, the tropical cyclone turned towards the west on 23 May and tracked into central Vietnam in response to ridging to the north over China.

With inflow from the extensive low-level southwest monsoonal flow, divergence aloft and weak vertical wind shear, Cecil reached typhoon intensity at 240000Z (Figure 3-04-1). The typhoon tracked across the coast of Vietnam at 241800Z with maximum sustained surface winds estimated at 70 kt (35 m/sec). News agencies reported that at least 52 people perished, 37 were injured, over 100,000 were left homeless and 700 water craft were destroyed. Persistent convection associated with Cecil produced heavy rains inland which resulted in flooding and crop damage in Laos and northeastern Thailand.

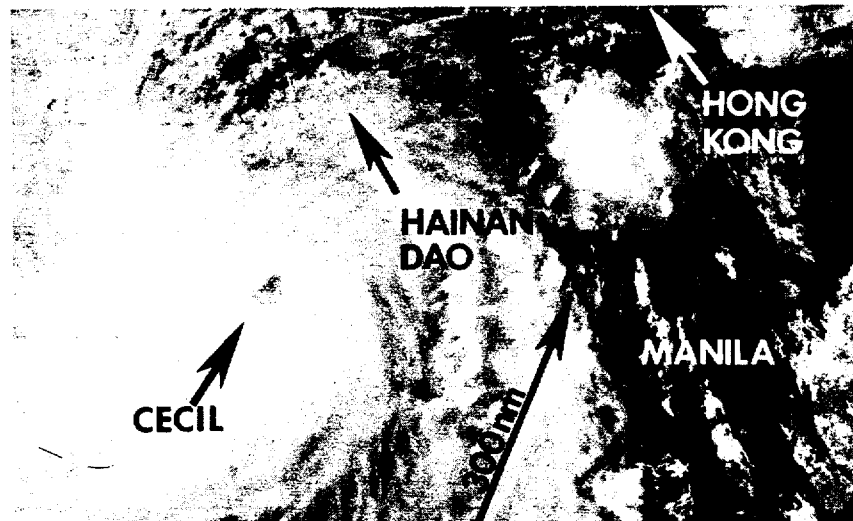
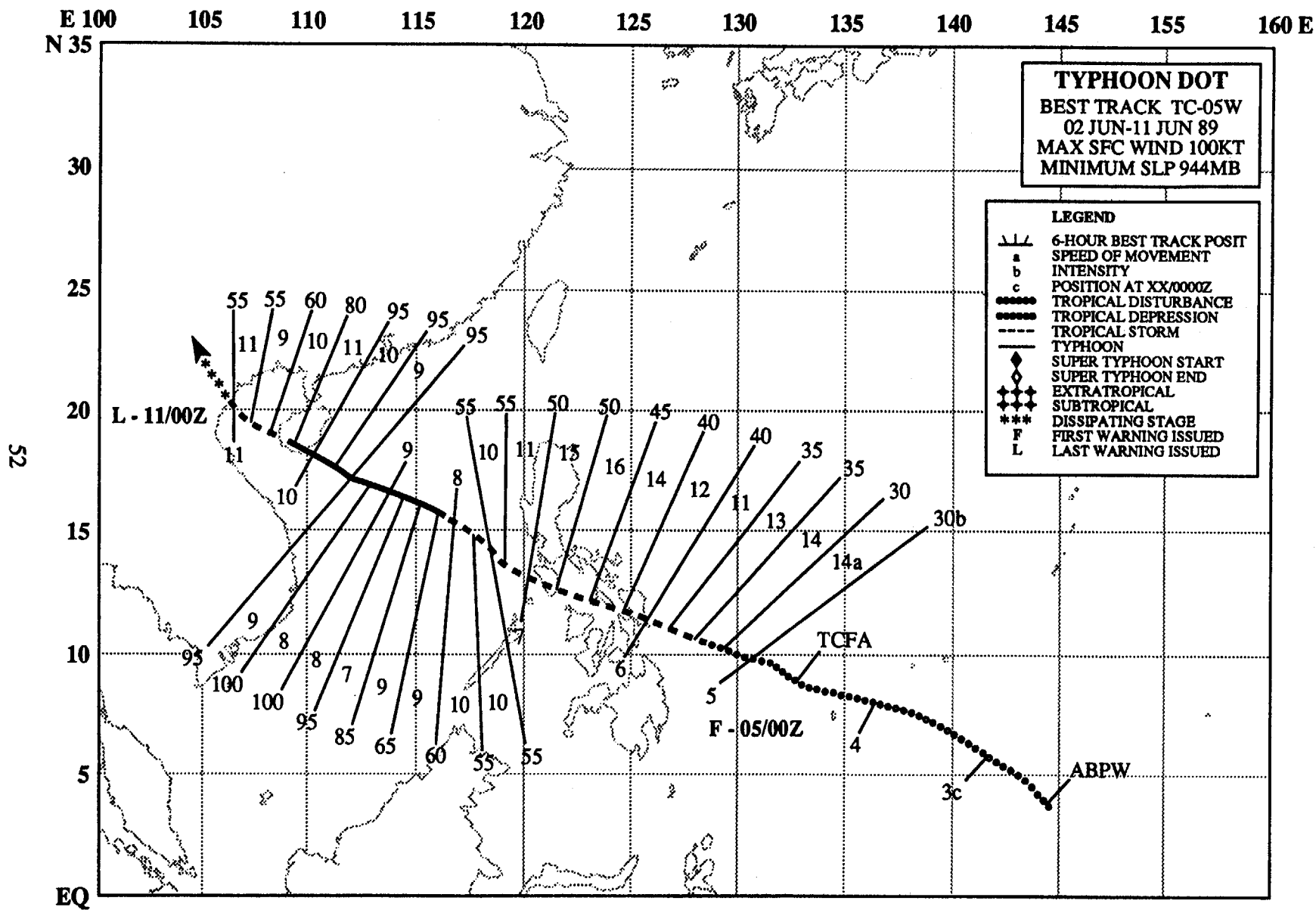


Figure 3-04-1. Cecil with a large ragged 40 nm (75 km) diameter eye approaches the coast of Vietnam (240539Z May NOAA visual imagery.)



TYPHOON DOT (05W)

Dot, the first of two significant tropical cyclones in June, formed in low latitudes south of the central Caroline islands, moved steadily west-northwestward and crossed the Philippine Islands. It reached typhoon intensity in the South China Sea and eventually dissipated over northern Vietnam.

After Cecil (04W) tracked across the South China Sea and into Vietnam the last week of May, the tropics were relatively quiet. Then light westerly surface winds appeared in the southern Philippine Sea and cloudiness increased. In this zone of maximum cloudiness on 2 June Dot, as a tropical disturbance, was

identified and noted in the Significant Tropical Weather Advisory as having fair potential for development. On 4 June the disturbance passed north of the island of Palau in the western Carolines and became better organized, which prompted a Tropical Cyclone Formation Alert at 041230Z. A further increase in convection and organization led to the first warning at 050000Z when the system was approximately 300 nm (555 km) southwest of the island of Samar in the Republic of the Philippines.

Tropical Depression 05W was upgraded to Tropical Storm Dot (Figure 3-05-1) at 051200Z, twelve hours before making

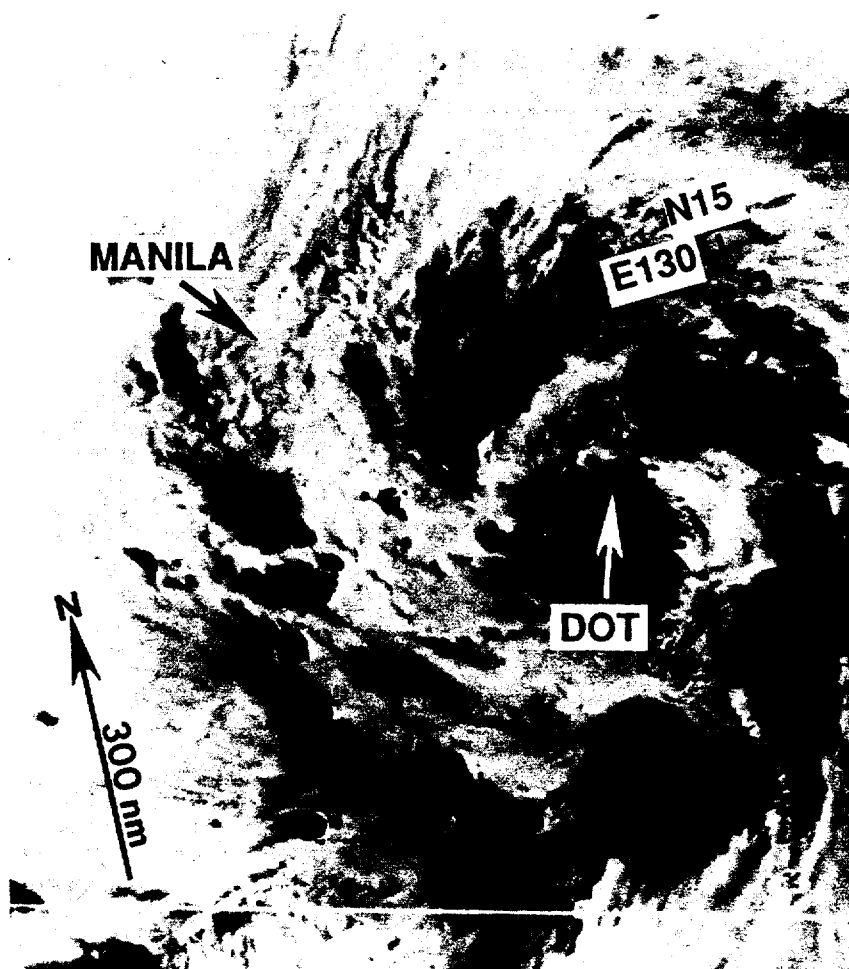


Figure 3-05-1. As Dot reaches tropical storm intensity, its central dense overcast and surrounding band of convection blanket a large portion of the Philippine Sea (051801Z June NOAA infrared imagery).

landfall on Samar. Dot accelerated slightly while crossing the central Philippine Islands which was in agreement with the results of Sikora's (1976) movement study. The open waters of the Sibuyan Sea and the relatively low relief of the adjacent islands allowed the circulation aloft to intensify slowly, but the rugged topography limited the surface effects. Clark Air Base's radar (WMO 98327) located the circulation center at 061835Z over south central Mindoro. As suspected from the previous satellite imagery, the analysis of surface pressure reports from land stations revealed the system's large size (Figure 3-05-2).

Upon entering the South China Sea, Dot initially took a more northward track. This increase in northward component, coupled with

the approaching frontal system and the guidance of most of JTWC's objective aids, led JTWC to forecast Dot's track to the east and north of Hainan Island (Figure 3-05-3). However, the tropical cyclone never linked up with the approaching frontal system and continued west-northwestward. Weak vertical wind shear and the warm waters of the South China Sea allowed Dot to reach typhoon intensity. Peaking at an intensity of 100 kt (51 m/sec) on 9 June (Figure 3-05-4), the typhoon then weakened as it approached and crossed southern Hainan Island. Dot crossed the Gulf of Tonkin as a tropical storm and made landfall near Haiphong, Vietnam at 110600Z. It dissipated six hours later in the mountains northwest of Hanoi.

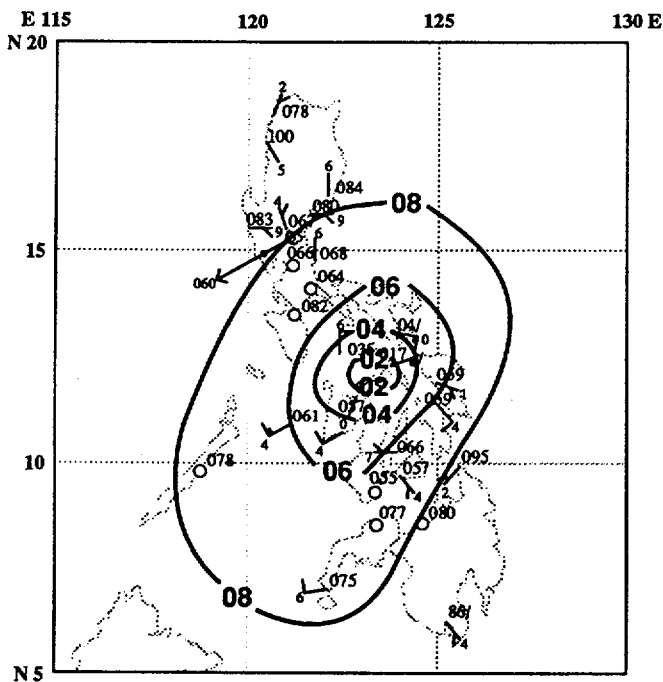


Figure 3-05-2. Based on the surface wind and pressure plots for 061200Z, the isobaric analysis shows the large size of the circulation.

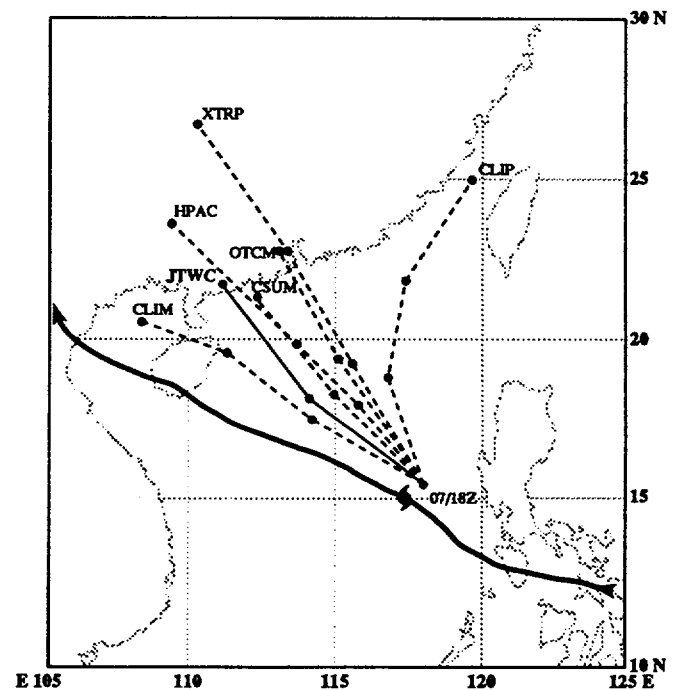


Figure 3-05-3. Objective guidance and the forecast from 071800Z through 24, 48 and 72 hours. Note: the displacement of the 071800Z starting point to the north of the best track. This is the result of adjustment to the best track caused by later data.

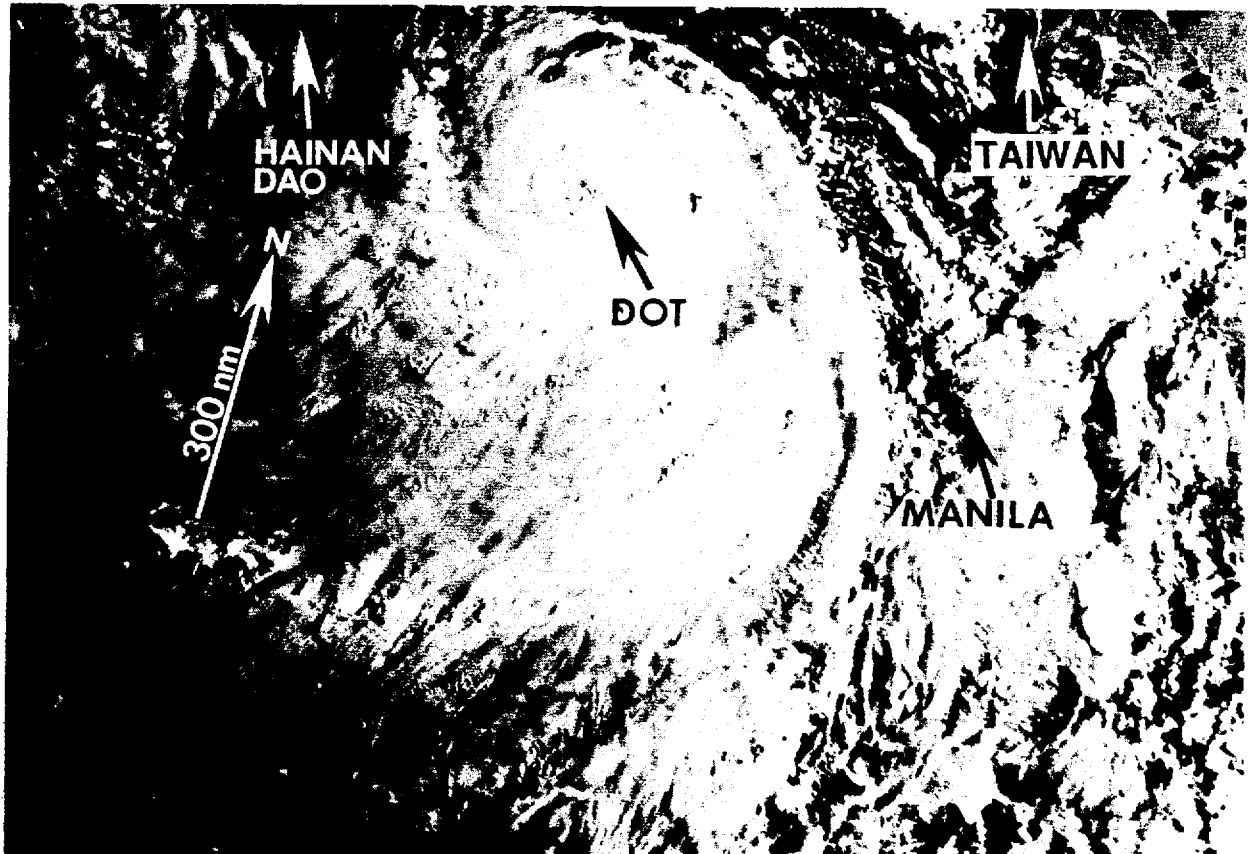
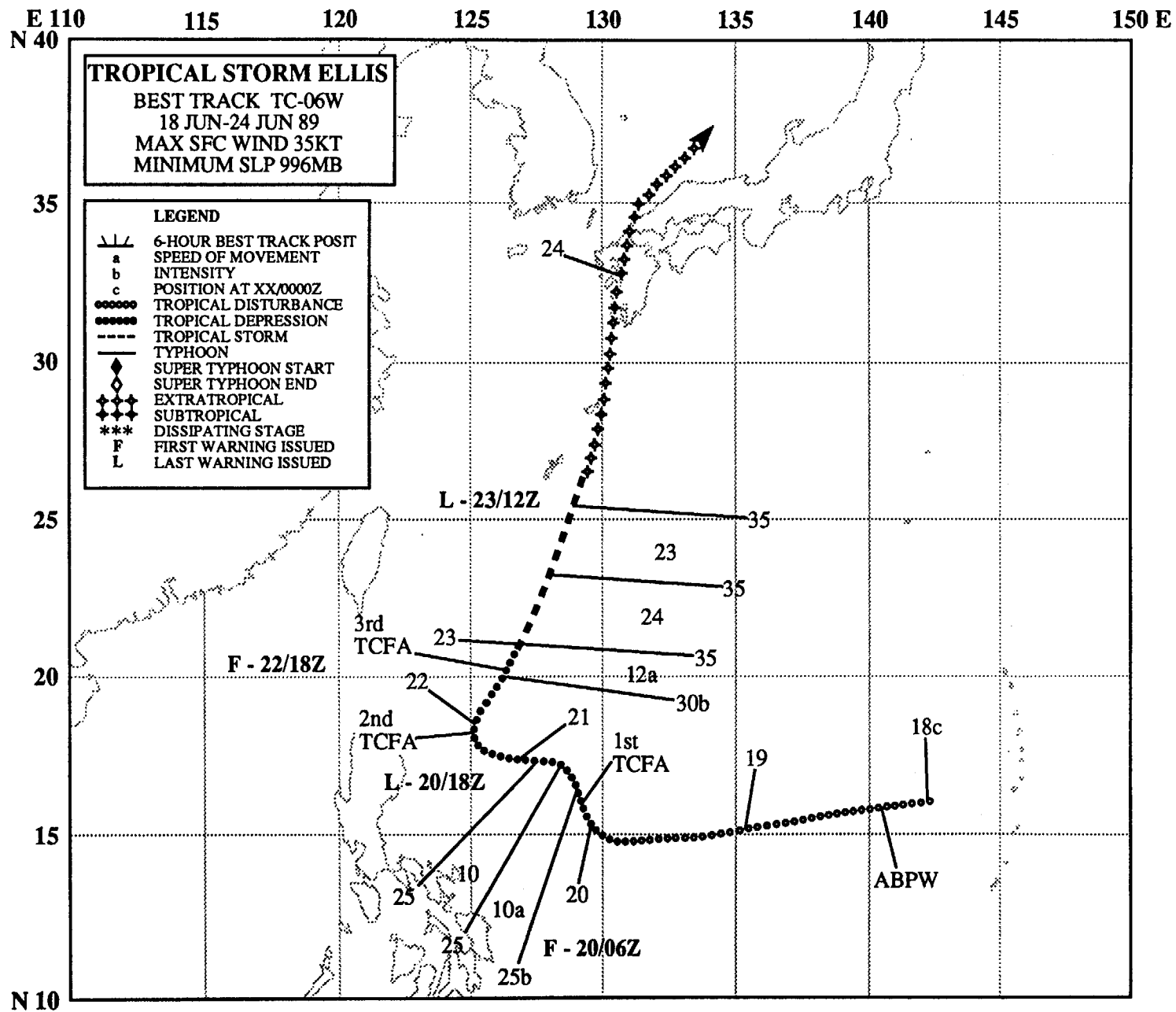


Figure 3-05-4. Nearing peak intensity, Typhoon Dot tracks towards Hainan Island (082225Z June DMSP visual imagery).



TROPICAL STORM ELLIS (06W)

The second of two tropical cyclones to form in June, Ellis interrupted the series of "straight runners" that occurred from Typhoon Brenda (03W) through Typhoon Dot (05W). After five days as a poorly defined system, Ellis briefly peaked at tropical storm intensity before becoming extratropical and making landfall in Japan. (This tropical cyclone provided the first opportunity for JTWC to use the newly instituted Tropical Depression Warning format as stated in a change to USCINCPACINST 3140.1T. This change addressed warnings when the depression was not expected to reach tropical storm intensity. These warnings were to be issued every twelve hours instead of every six hours as is the case for Tropical Cyclone Warnings.)

On 18 June, a disturbance formed in the Philippine Sea 210 nm (390 km) northwest of Guam and was mentioned on the Significant Tropical Weather Advisory. The disturbance was classified as having poor potential for further development, due to the lack of favorable upper-level support. It appeared that the proximity of the TUTT to the north through northeast restricted the outflow from the convection. However, the next Advisory was reissued at 192100Z to upgrade the potential for further development to fair after the central convection flared at the morning convective maximum and synoptic data revealed the development of the low level cyclonic circulation. A Tropical Cyclone Formation Alert followed at 200430Z when the deep convection had persisted. Within ninety minutes, the first Tropical Depression Warning was issued. The application of the Tropical Depression Warning was appropriate since this depression (Figure 3-06-1) appeared deeply embedded in the monsoon trough and further development was unlikely. At 201800Z, the second, and final, Tropical Depression Warning followed as the poorly defined cloud system weakened 450 nm (835 km) east of Luzon.

As the disturbance moved westward toward Luzon, the 200 mb pattern underwent a substantial change. On 18 June, a narrow ridge aloft with an east to west orientation extended through the Bonin Islands (south of Japan). Simultaneously, a weak trough existed across Korea and western Honshu. Short waves exiting China deepened this trough until it extended southward from the Yellow Sea to Taiwan. The rawinsonde data from Okinawa (WMO 47936) showed 60-meter height falls at 200 mb from 19 to 20 June. This adjustment of the upper-level pattern favorably positioned divergence over the remnants of the tropical depression.

With synoptic data indicating minimum sea-level pressures near 1001 mb, the next convective flare up prompted a second Alert at 211900Z. Then, with the synoptic situation unchanged, a third Alert followed 24 hours later. This Alert addressed the fact that the maximum winds were displaced 180 nm (335 km) east of the system's center. This asymmetric displacement of a broad area of gales away and to the east of the low-level circulation center was unusual and accompanied Ellis for the remainder of its lifetime. At 222100Z, JTWC issued the first Tropical Cyclone Warning on Tropical Depression 06W (Figure 3-06-2). The system was forecast to move slowly toward the northeast, steered by the southwesterly flow ahead of the trough. Further, it would only reach minimal tropical storm intensity before encountering increased vertical wind shear and cooler air behind a stationary front. The front had pushed south of Okinawa during the preceding three days.

While the intensity was correctly forecast, Tropical Storm Ellis led JTWC on a high speed chase, doubling its forward speed from 12 to 24 kt (6 to 12 m/sec) as it sped toward Okinawa. By the fourth warning at 231200Z, Ellis was becoming extratropical, having linked with the previously mentioned stationary front; but it was not weakening. The

system passed 90 nm (165 km) east of Kadena AB. Kadena (WMO 97931) provided two radar fixes on Ellis, as it passed by, and reported peak gusts to 22 kt (11 m/sec). The system passed over Kyushu and extreme western Honshu

before dissipating over the Sea of Japan on 24 June. Although gales persisted as Ellis continued northward, no reports of major damage or fatalities were received.

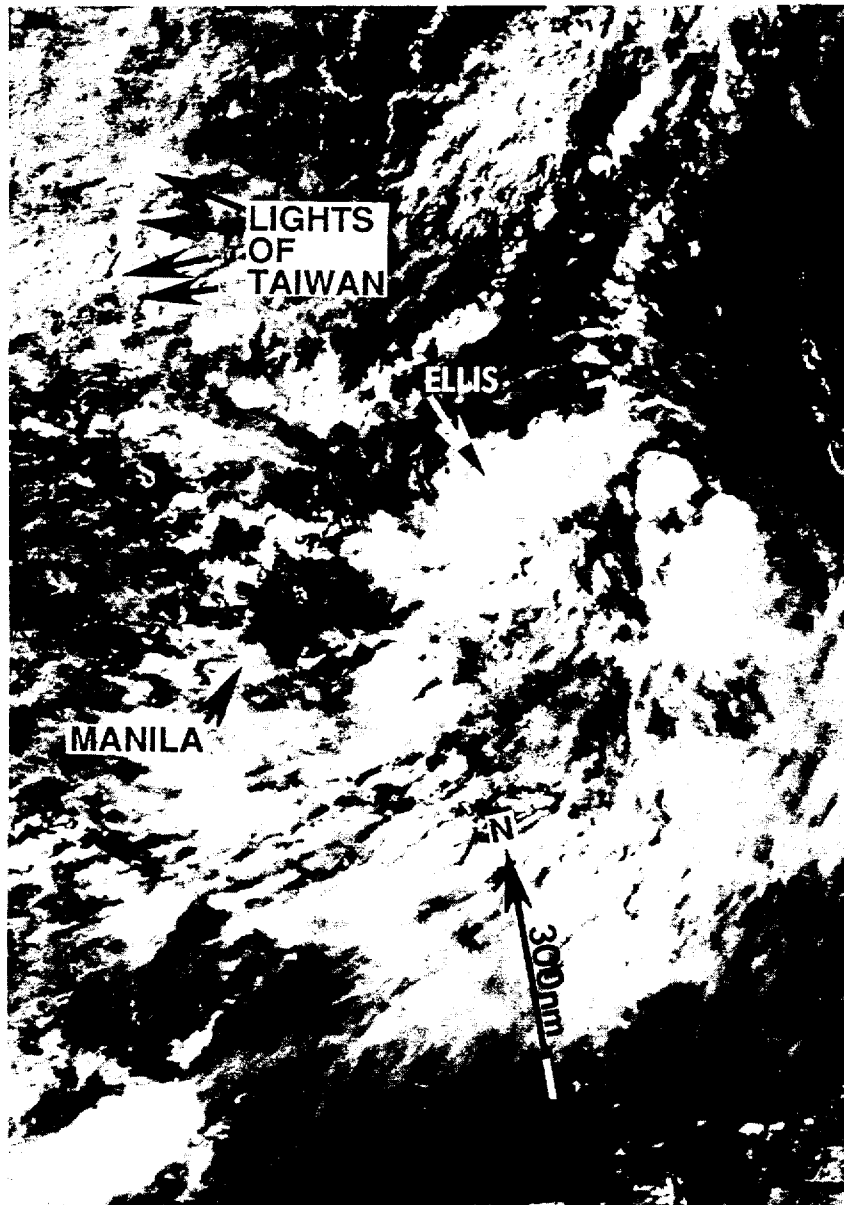


Figure 3-06-1. Nighttime visual picture of the disorganized cloud signature of the tropical depression after the first warning. Bright moonlight makes the image look like daytime. Note the city lights of Taiwan (201327Z June DMSP visual imagery).

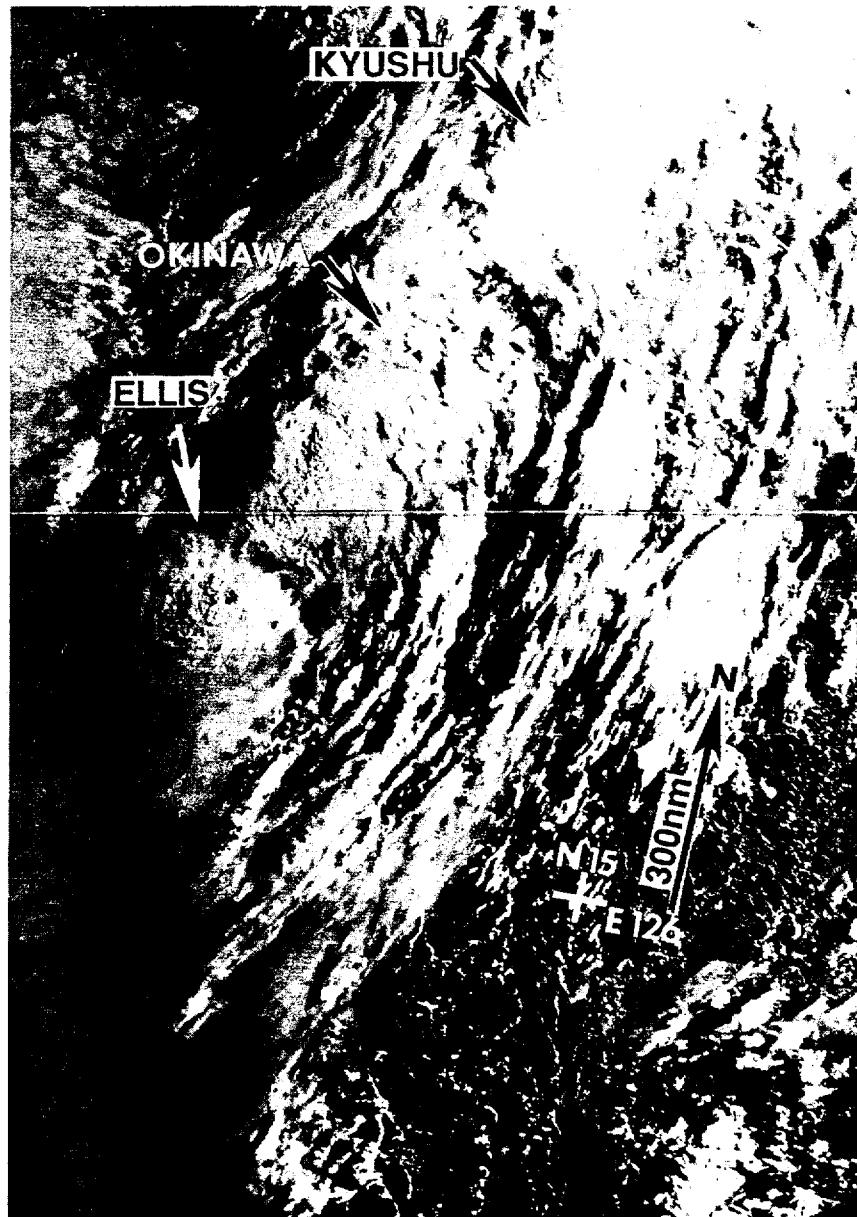
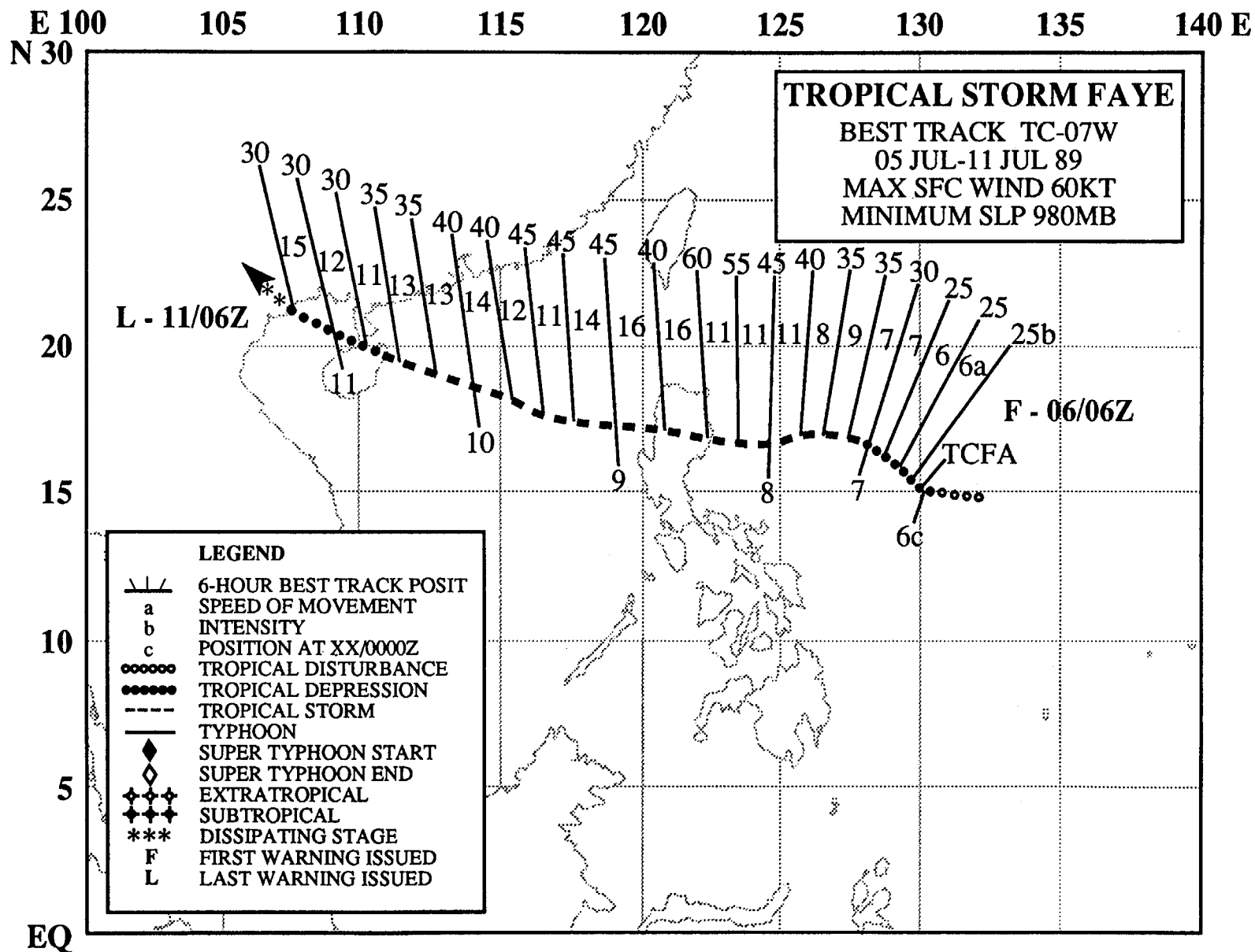


Figure 3-06-2. Ellis starts moving northward towards Okinawa (222106Z June DMSP visual imagery).



TROPICAL STORM FAYE (07W)

After a two-week break in activity, Faye was the first of seven tropical cyclones to form in July. It formed in the monsoon trough and intensified at a normal rate as it tracked west-northwestward towards the Philippines. Faye weakened as it crossed north-central Luzon and reintensified slightly in the South China Sea. It weakened again in the central South China Sea, and crossed the island of Hainan before making landfall on the coast of northern Vietnam.

On 4 July, a surge in the southwest monsoon caused a widespread increase of convective activity in an area west of the Mariana Islands. This convection was short-lived — peaking at 050000Z and dissipating for the most part by 051200Z. Out of the remnants of this convection arose a small area of deep convection near 15° north latitude and 130° east longitude. This deep convection continued to

develop after the early morning convective maximum, and at 060200Z a Tropical Cyclone Formation Alert was issued on the disturbance. The first tropical cyclone warning on Tropical Depression 07W followed at 060600Z. At that time, the depression had a partially exposed low-level circulation to the north of the deep convection with restricted upper-level outflow in the northern semicircle. This displacement of convection introduced some uncertainty in the location of the low-level circulation center (Figure 3-07-1) until first light the next day.

A short wave trough passing to the north induced a small northward shift in track during the first 24 hours in warning. As the short wave trough moved eastward, the subtropical ridge strengthened to its west and the depression began moving to the west. Continued development resulted in an upgrade to tropical

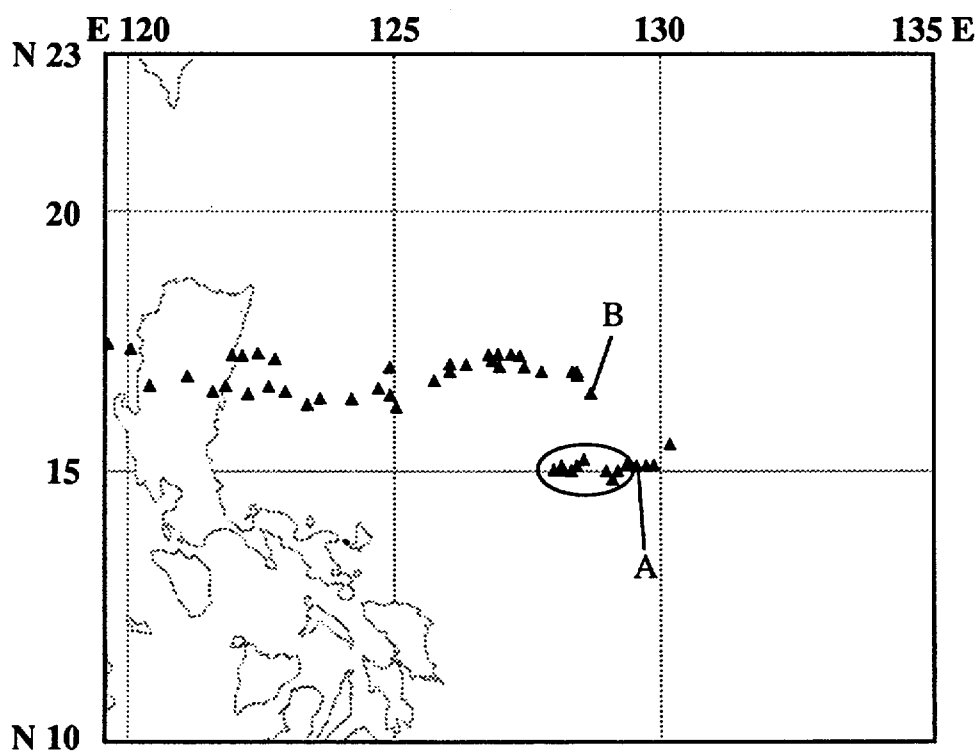


Figure 3-07-1. After the last visual fix at 060730Z (point A), plots of satellite fixes (encircled) through the night show that cold cloud top targets on the infrared imagery can be misleading. The visual data the next day at 062330Z (point B) enabled the forecaster to get the weak circulation back on track.

storm intensity at 070600Z. Throughout the next 24 hours, the subtropical ridge remained unchanged and Faye tracked westward and intensified.

Tropical Storm Faye reached its peak intensity of 60 kt (31 m/sec) at 081200Z, just prior to making landfall in north-central Luzon. Remarks from the radar site at Baguio (WMO 98321) about the change of wind direction from northwest to southwest and 35 kt (18 m/sec) gusts proved invaluable in tracking Faye as it accelerated over Luzon and retained tropical storm intensity as it entered the warm waters of the South China Sea late on 8 July. Moving out into open waters, it began to reintensify. In the central South China Sea, Faye moved into an

environment of strong upper-level north-easterlies which began to shear the system. Despite this strong shear, Faye (Figure 3-07-2) retained much of its convective organization and its tropical storm intensity until it reached the island of Hainan.

Late on the 10 July, Faye crossed northern Hainan causing telecommunication interruptions and the destruction of pepper, sugar cane and coffee crops. It was downgraded to a tropical depression as it entered the Gulf of Tonkin. The low-level circulation, which was displaced 45 nm (85 km) from the deep convection, made landfall near Haiphong, Vietnam at 110600Z and quickly dissipated.

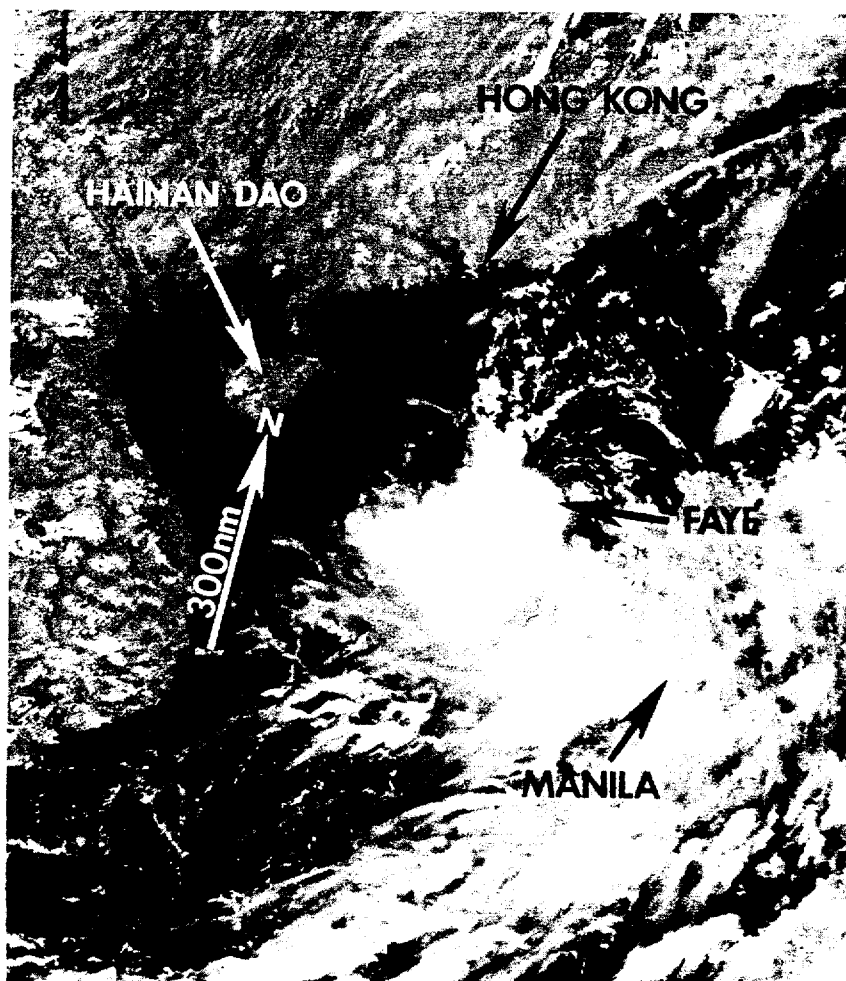
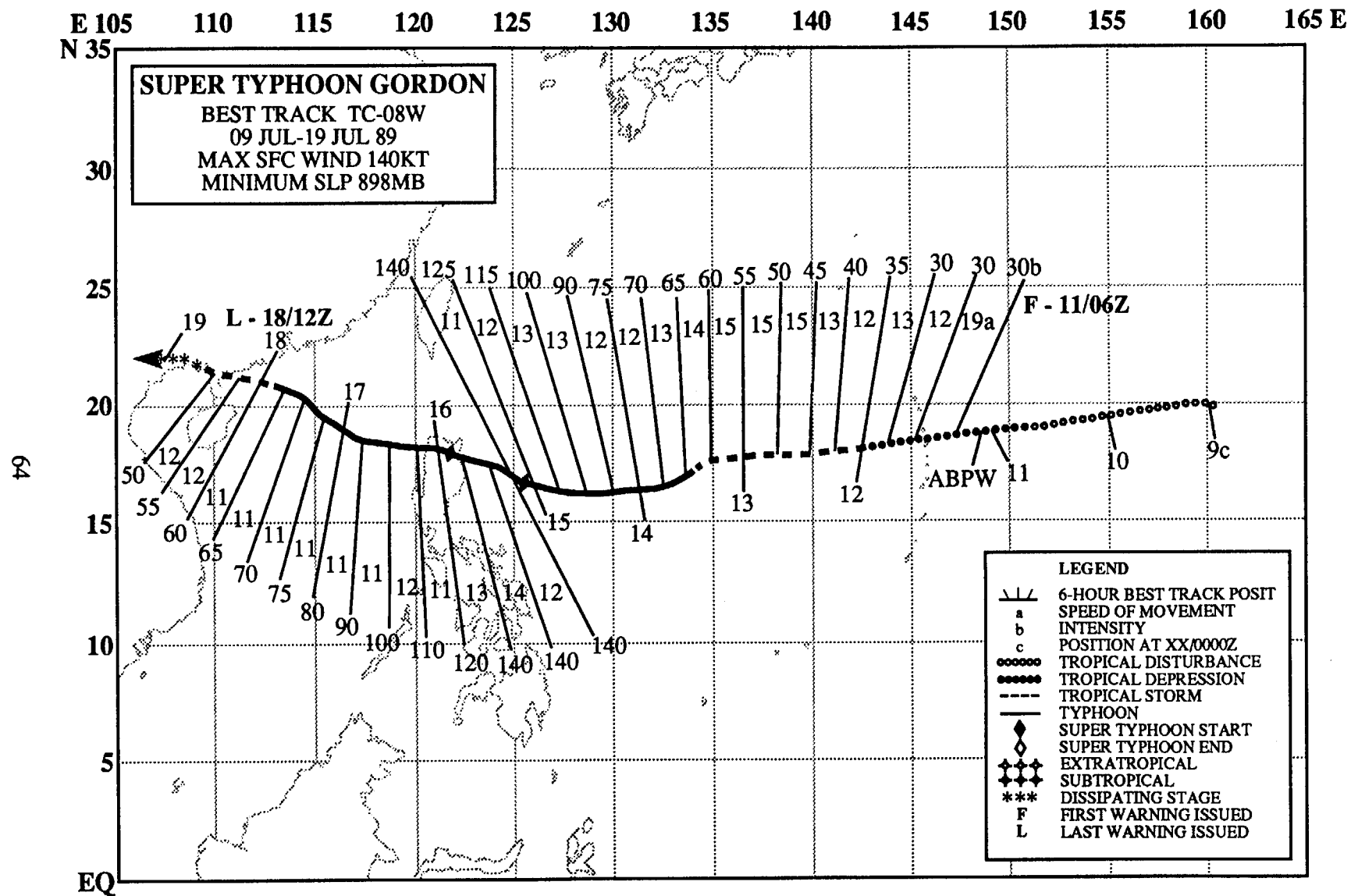


Figure 3-07-2. The exposed low-level circulation center is evidence of a shearing regime in the South China Sea (090607Z July NOAA visual imagery).

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SUPER TYPHOON GORDON (08W)

The second super typhoon in the western North Pacific for 1989, Gordon was also the second of seven significant tropical cyclones to form in July. The system was unique in that it developed from a single cumulonimbus directly beneath a cyclonic cell in the Tropical Upper-Tropospheric Trough (TUTT). The cumulo-

nimbus was initially small, but underwent a dramatic rapid, almost explosive, deepening phase.

At the start of the second week of July, Tropical Storm Faye (07W) was affecting the Philippine Islands. Aloft, the TUTT, which

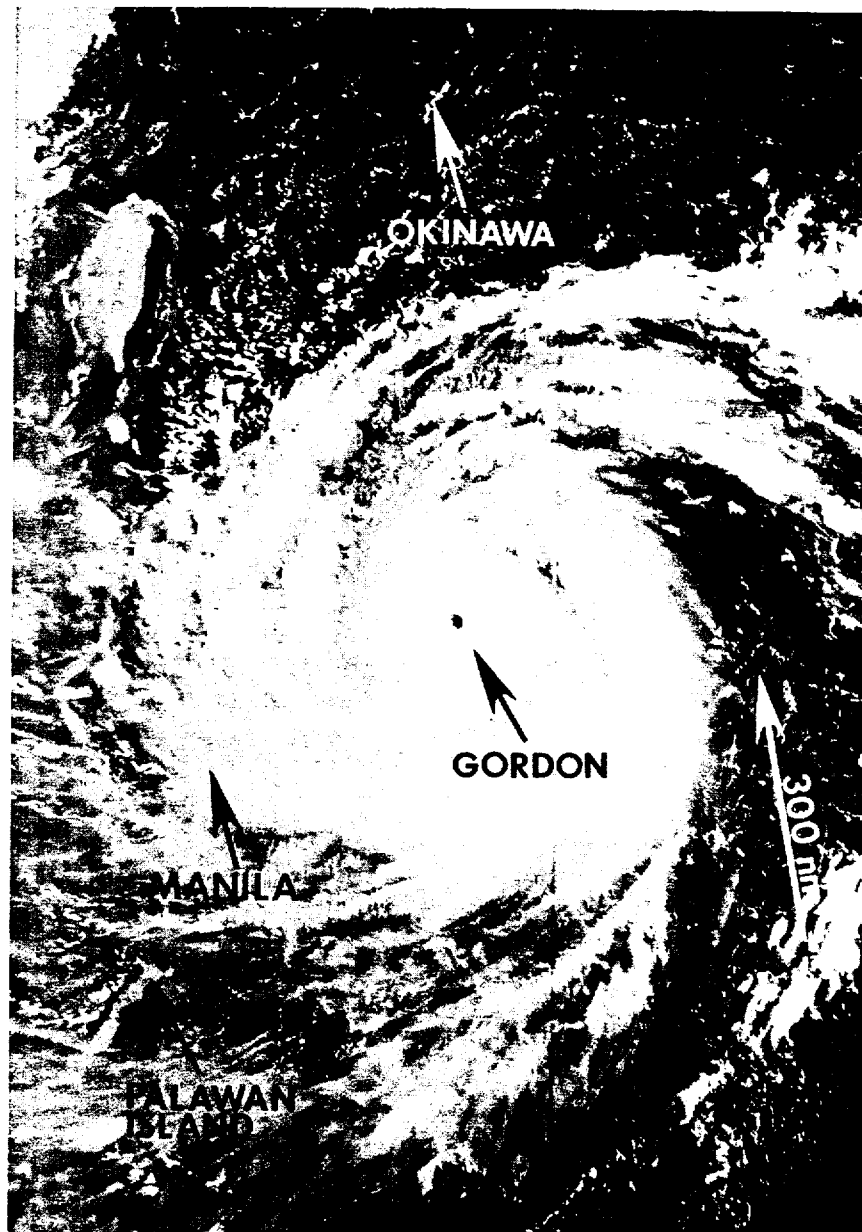


Figure 3-08-1. Typhoon Gordon four hours before reaching super typhoon intensity. The eye diameter is 20 nm (37 km) (142304Z July DMSP visual imagery).

extended eastward, was the major upper-tropospheric feature. It overlaid an extensive cloud minimum area that extended eastward to the date line. Just to the west of Wake Island on 9 July, a discrete cloud system became associated with a deep TUTT low.

On 11 July after the early morning convective maximum, a very small, ragged central dense overcast persisted, and the Significant Tropical Weather Advisory was reissued at 110200Z to include the system. Subsequent satellite imagery indicated the system's vigorous central convection was expanding rapidly, too rapidly to enable JTWC to issue a Tropical Cyclone Formation Alert. As a result, an abbreviated warning was issued on Tropical Depression 08W at 110400Z, followed by the first 72-hour warning at 110600Z. This development was unusual. Gordon appeared to blossom directly beneath the upper cold low. This was in contrast to the normal sympathetic development of convection to the south and east of the upper low (Sadler, 1976). To our knowledge such a distal development has never been documented. Sadler (1974) does discuss a similar development where convection wraps around the TUTT cell, finally converting the cold-core cyclone to a warm-core one. This is generally a slow process. He also alludes to occasional cumulonimbus near the center of TUTT cells as a clue to locating their centers, but does not discuss the development of tropical cyclones from the thunderstorms.

The system's track was west-southwest to westward for two days, becoming west-northwestward as Gordon approached the Philippine Islands. The guidance from the NOGAPS fields correctly foretold that no break in the subtropical ridge would occur, and that Gordon's westward movement would be uninterrupted.

Initially, forecasters expected slow to normal intensification as the TUTT restricted the system's upper-level outflow. However, the depression was quickly upgraded to Tropical

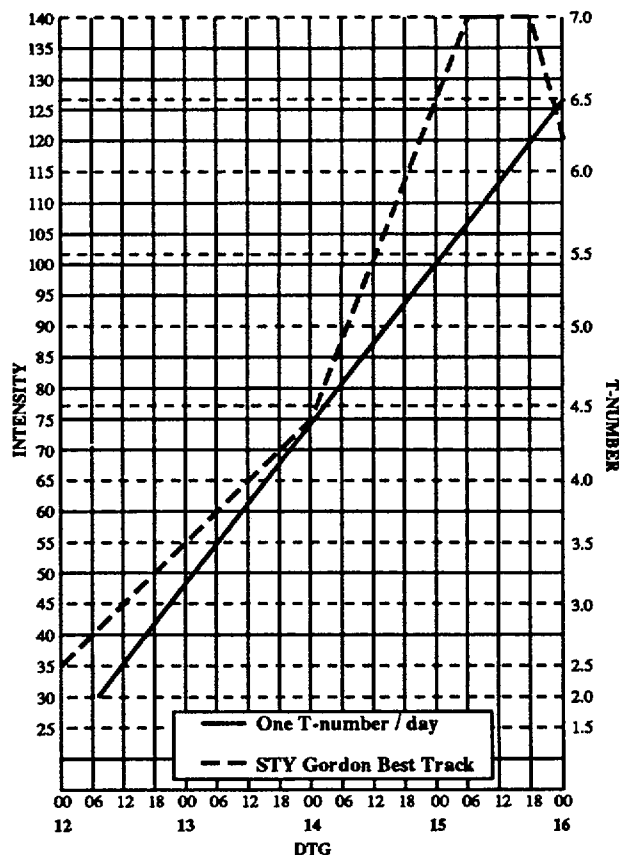


Figure 3-08-2. Gordon's rapid intensification after 140000Z compared with an increase of one "T" number per day.

Storm Gordon 24 hours after the initial warning, to typhoon after 48 hours, and to super typhoon after 96 hours (Figure 3-08-1). In only 30 hours from 140000Z to 150600Z, Gordon intensified rapidly - two-and-one-half "T" numbers (Figure 3-08-2). This represents an estimated 70-mb fall in central pressure over this period, or a deepening rate of 2.3 mb/hr, just short of the 2.5 mb/hr required for explosive deepening (Dunnavan, 1981).

Super Typhoon Gordon slammed into the rice-producing region of northern Luzon with maximum sustained winds of 140 kt (72 m/sec). News reports indicated that 27 people died, 15 were missing, at least 120,000 were evacuated and thousands were left homeless in its wake. To the south, the peak winds reported from US military installations in the Philippines were 68 knots (35 m/sec) at Wallace AS, 54

knots (28 m/s) at John Hay AB, 40 kt (21 m/sec) at Cubi Point NAS (WMO 98426), and 18 kt (9 m/sec) at Clark AB (WMO 98327). John Hay AB also recorded a total of 29.8 inches (747 mm) of rain. The SS OVERSEAS VIVIAN reported 35 kt (18 m/sec) sustained winds as it approached Subic Bay late on 15 July when Gordon was more than 200 nm (370 km) away.

After exiting northern Luzon, the

typhoon moved west-northwestward across the South China Sea and passed 100 nm (185 km) to the southwest of Hong Kong at 171800Z (Figure 3-08-3). U.S. Navy ships in port at Hong Kong had sortied 24 hours earlier. Though the system was weakening as it made landfall near the coastal city of Zhanjiang, 215 nm (398 km) west-southwest of Hong Kong, where Gordon inflicted more fatalities and property loss. The final warning was issued at 181200Z, as Gordon left the Leizhou peninsula.

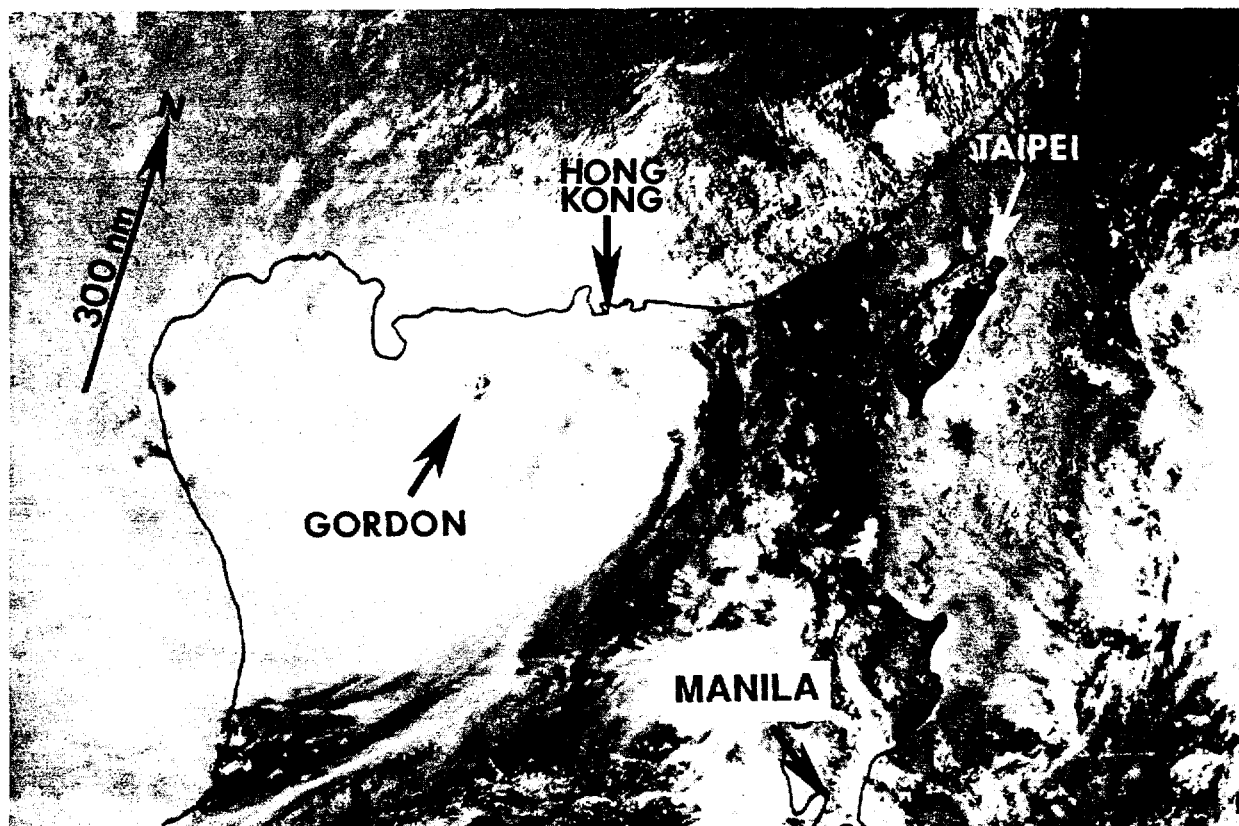


Figure 3-08-3. The large ragged eye is visible as Tropical Storm Gordon moves southwest of Hong Kong (180126Z July DMSP visual imagery).

During the next three hours, Gordon's area of convection (Figure 3-08-4) expanded nearly three times in size as it moved across the shallow, warm waters of the Gulf of Tonkin. Synoptic data indicated continued weakening

during the convective expansion. The remnants of Gordon were identifiable on satellite imagery for the next 24 hours as the dissipating system moved into the mountains of northern Vietnam.

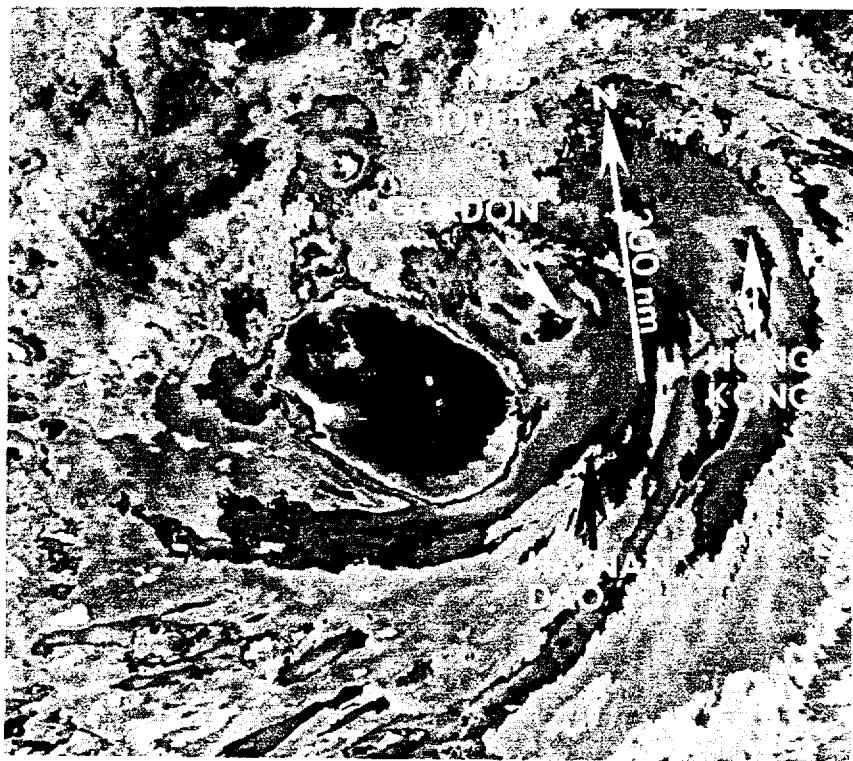
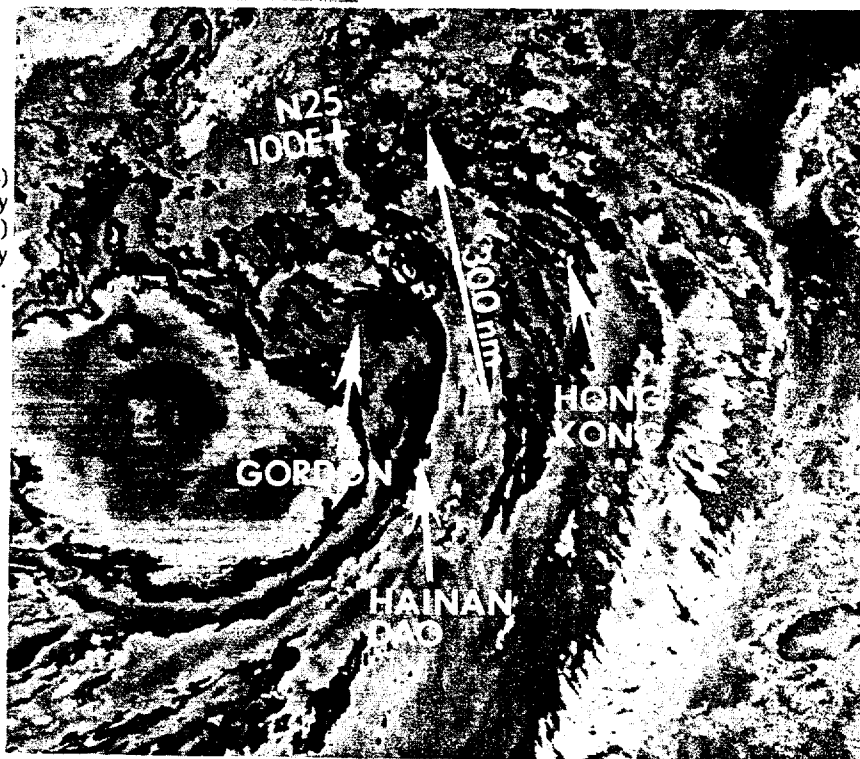
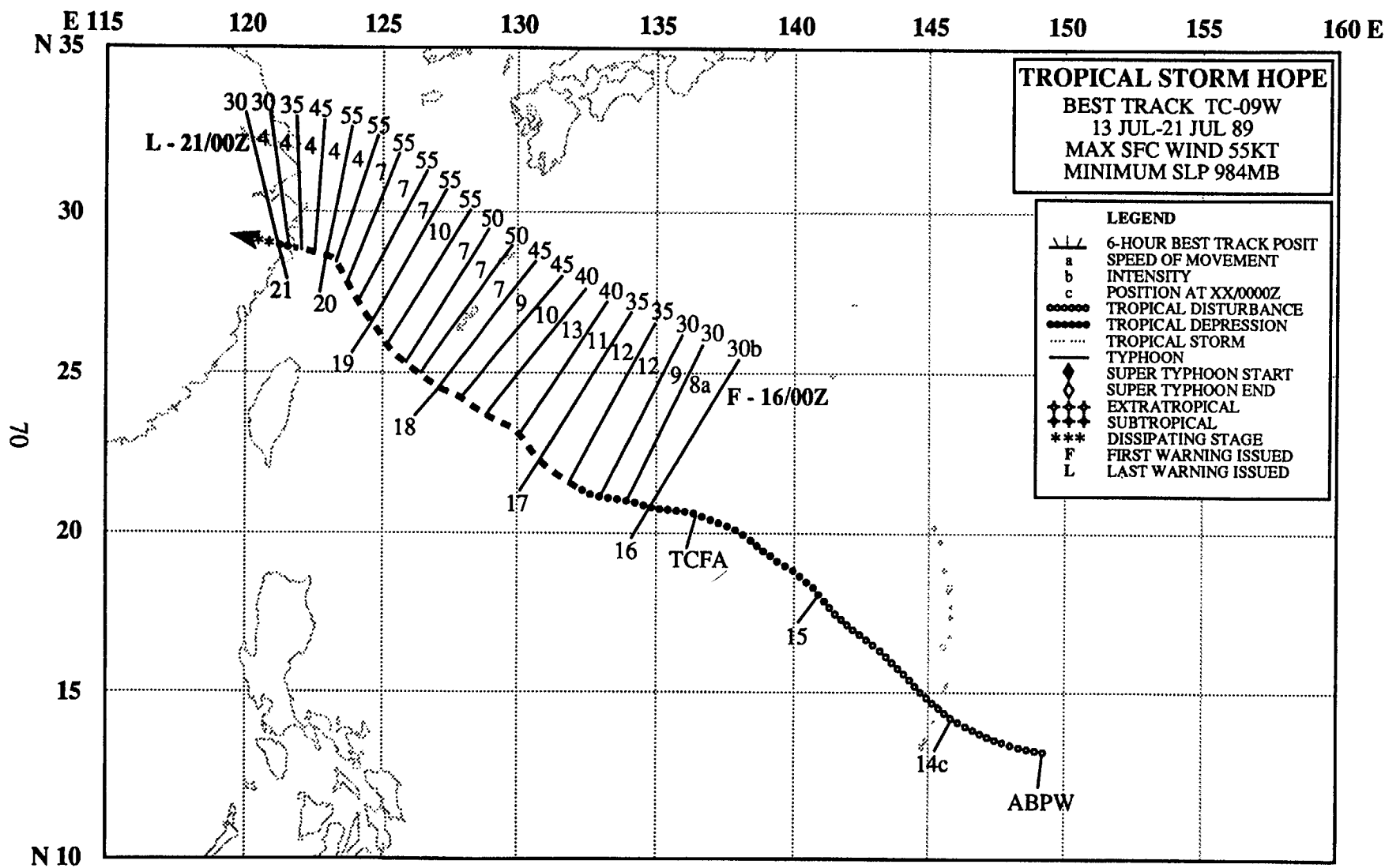


Figure 3-08-4. Tropical Storm Gordon (above) enters northern Gulf of Tonkin (181115Z July DMSP enhanced infrared imagery) and (below) Gordon's area of convection expands rapidly (181407Z July DMSP enhanced infrared imagery).



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TROPICAL STORM HOPE (09W)

The third of seven tropical cyclones to form in July, Hope was a TUTT-induced tropical cyclone that failed to develop to typhoon intensity as a result of the upper-level shear from outflow from Super Typhoon Gordon (08W). During its life, Hope moved generally northwestward, occasionally "stair-stepping" in response to the passage of a series of mid-latitude short-wave troughs. Although no binary interaction was apparent, the tropical cyclone tracked along the periphery of Gordon's low-level inflow for most of its lifetime.

Hope generated in the wake of Gordon (08W) in a broad area of convection enhanced by the divergence aloft associated with a TUTT cell. When the convection persisted for more than 18 hours, it was included as a suspect area on the Significant Tropical Weather Advisory at 130600Z. Synoptic data indicated a low-level cyclonic circulation embedded in the convection. Surface winds were estimated to be 10 to 20 kt (5 to 10 m/sec) and the MSLP 1007 mb. During the next 48 hours, the convection became disorganized due to increased vertical wind shear aloft from Super Typhoon Gordon (08W), which was intensifying to the west. A weak surface circulation persisted in the synoptic data.

At 151740Z JTWC issued a Tropical Cyclone Formation Alert when Hope's central convection increased after the combined

restrictive effects of the passage of a mid-latitude trough to the north and outflow from Gordon (08W) to the west decreased. Winds in the area were estimated to be 20 to 30 kt (10 to 15 m/sec). The first warning followed at 160000Z. Tropical Depression 09W tracked westward for the next 18 hours under the influence of the building mid-tropospheric subtropical ridge to the north. The low-level circulation center remained partially exposed until 161800Z, when a central dense overcast formed. In response, Hope intensified to 35 kt (17 m/sec) and was upgraded to a tropical storm.

Late on 16 July, Hope's track returned to the northwest in contrast to the guidance provided by the NOGAPS forecast fields, which indicated the subtropical ridge would remain intact despite the approach of a series of short-wave troughs. The NOGAPS guidance was reinforced by the statistical-dynamic aid CSUM. As a result, JTWC adjusted the forecast track southward with each succeeding warning until, by 171800Z, Hope was forecast to pass near Taiwan. However, the tropical cyclone remained north of the forecast track and slowly intensified. Kadena AB (WMO 47931) on Okinawa, approximately 100 nm (185 km) northeast of the tropical storm, measured a peak gust of 31 kt (16 m/sec) at 180411Z.

From 180000Z through 191800Z the

synoptic situation was complex (Figure 3-09-1). Hope responded to another short-wave trough and tracked north-northwestward. Once again JTWC abandoned the westward track into China and changed the forecast track to take Hope through a possible break in the subtropical ridge into the East China Sea and then on to Korea. The change in track was prompted by several factors: (1) the failure of the expected westward movement to develop, (2) the

possibility that NOGAPS was overforecasting the strength in the ridge to the north, (3) the expectation that Hope would remain a shallow system and be influenced by the more southerly low- to mid-level steering flow rather than the weak easterly mid- to upper-level flow, and (4) guidance from the dynamic aid OTCM. However, after the passage of another short-wave trough, the ridge strengthened north of Hope. At 200000Z, the tropical storm (Figure

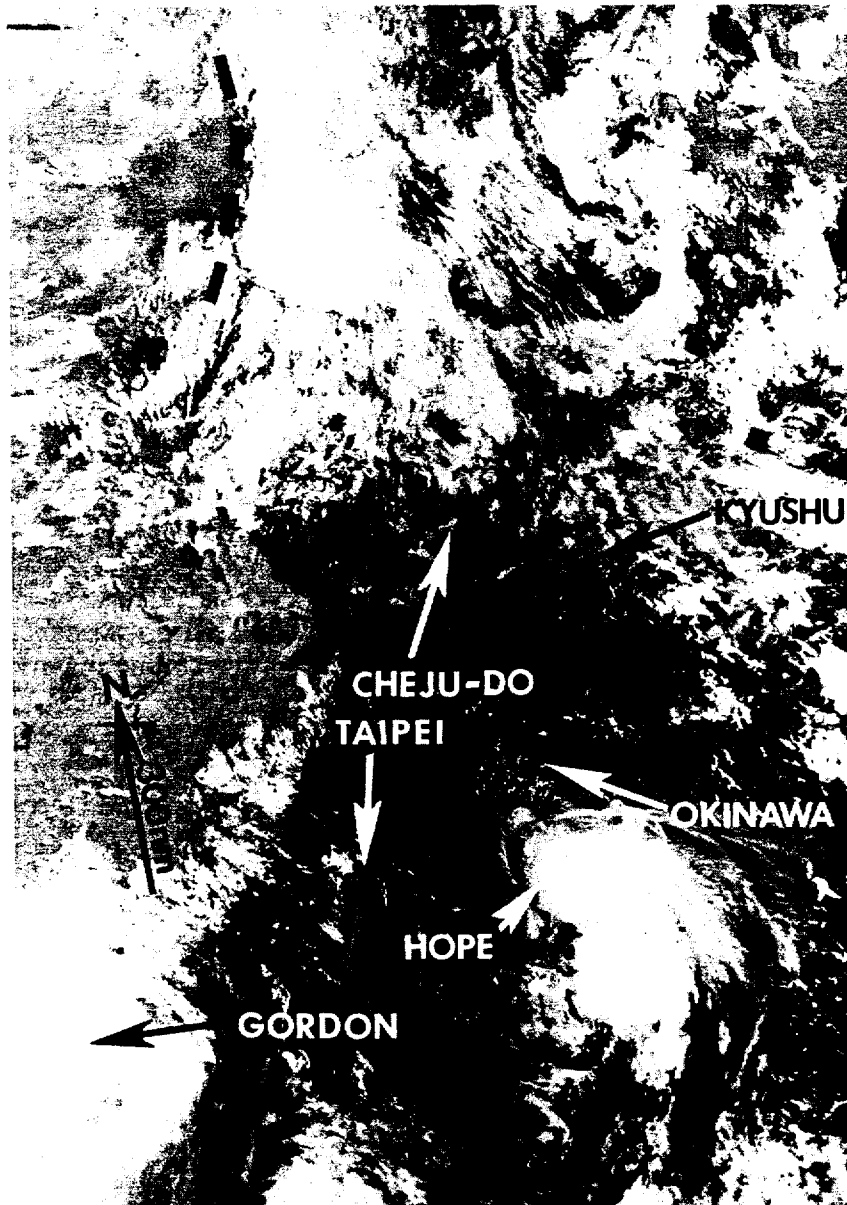


Figure 3-09-1. Complex synoptic situation with Gordon (08W) to the west, and the mid-latitude trough to the north. The island of Okinawa is nearby (172338Z July NOAA visual image).

3-09-2) executed an abrupt turn to the west and moved into mainland China.

While Hope was over warm ocean waters, it intensified slowly, reaching its peak intensity of 55 kt (27 m/sec) at 181800Z. However, the northeasterly upper-level flow restricted Hope's outflow and prevented further development into a typhoon. Hope was down-

graded to a tropical depression at landfall. The tropical cyclone weakened rapidly as it moved over land, and the final warning was issued at 210000Z. News reports indicated that at least 24 people died and more than 1000 were injured in eastern China. In addition, landslides and widespread flooding resulted from locally heavy rains. Totals up to 7.5 inches (109 mm) in 24 hours were recorded in some areas.

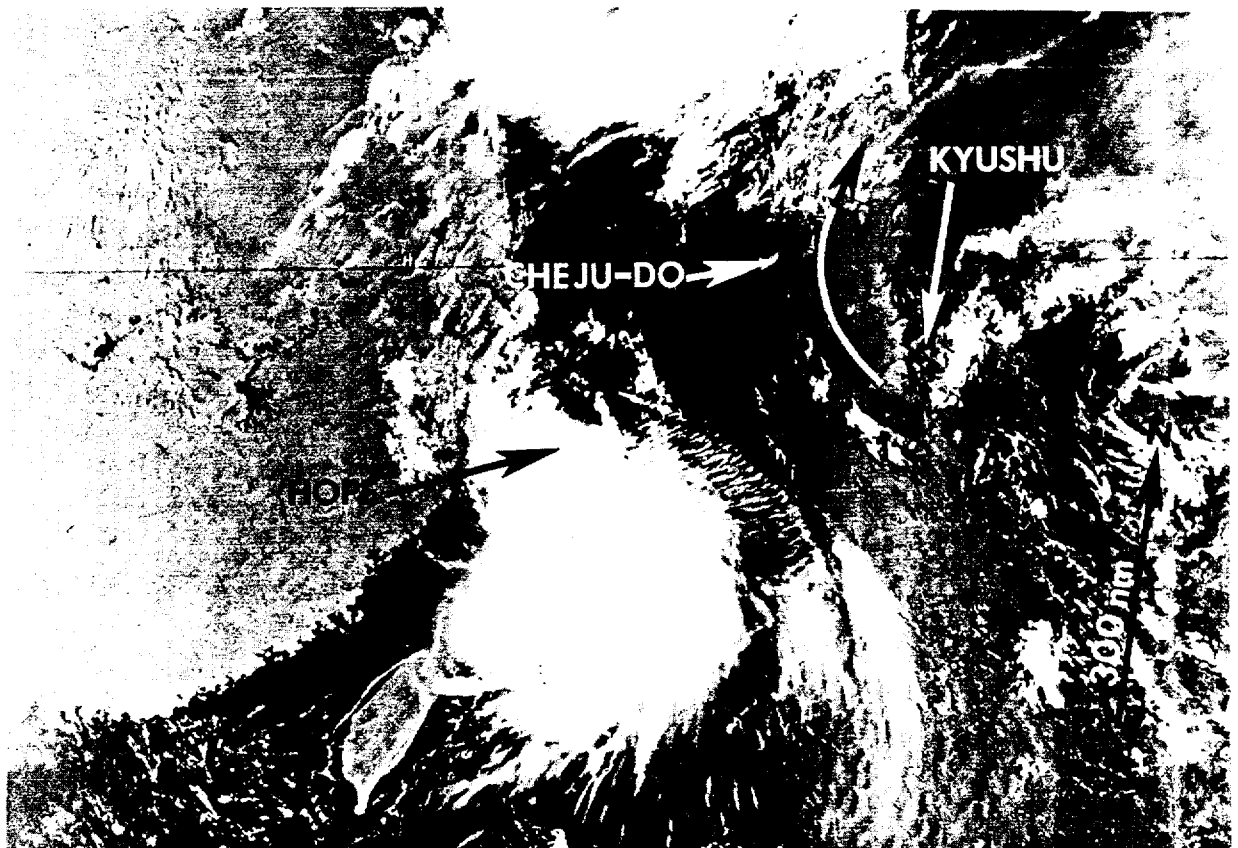


Figure 3-09-2. Hope near landfall. The low-level anticyclonic flow (indicated by the curved arrow) in the subtropical ridge is defined by the cumulus streets across southern Korea, coastal China, and the brightness pattern in the lee of Kyushu. Frontal cloudiness associated with the passing trough trails across central Korea and the Yellow Sea (200046Z July DMSP

E 100 105 110 115 120 125 130 135 140 145 E
N 30

TROPICAL STORM IRVING

BEST TRACK TC-10W

18 JUL-24 JUL 89

MAX SFC WIND 55KT

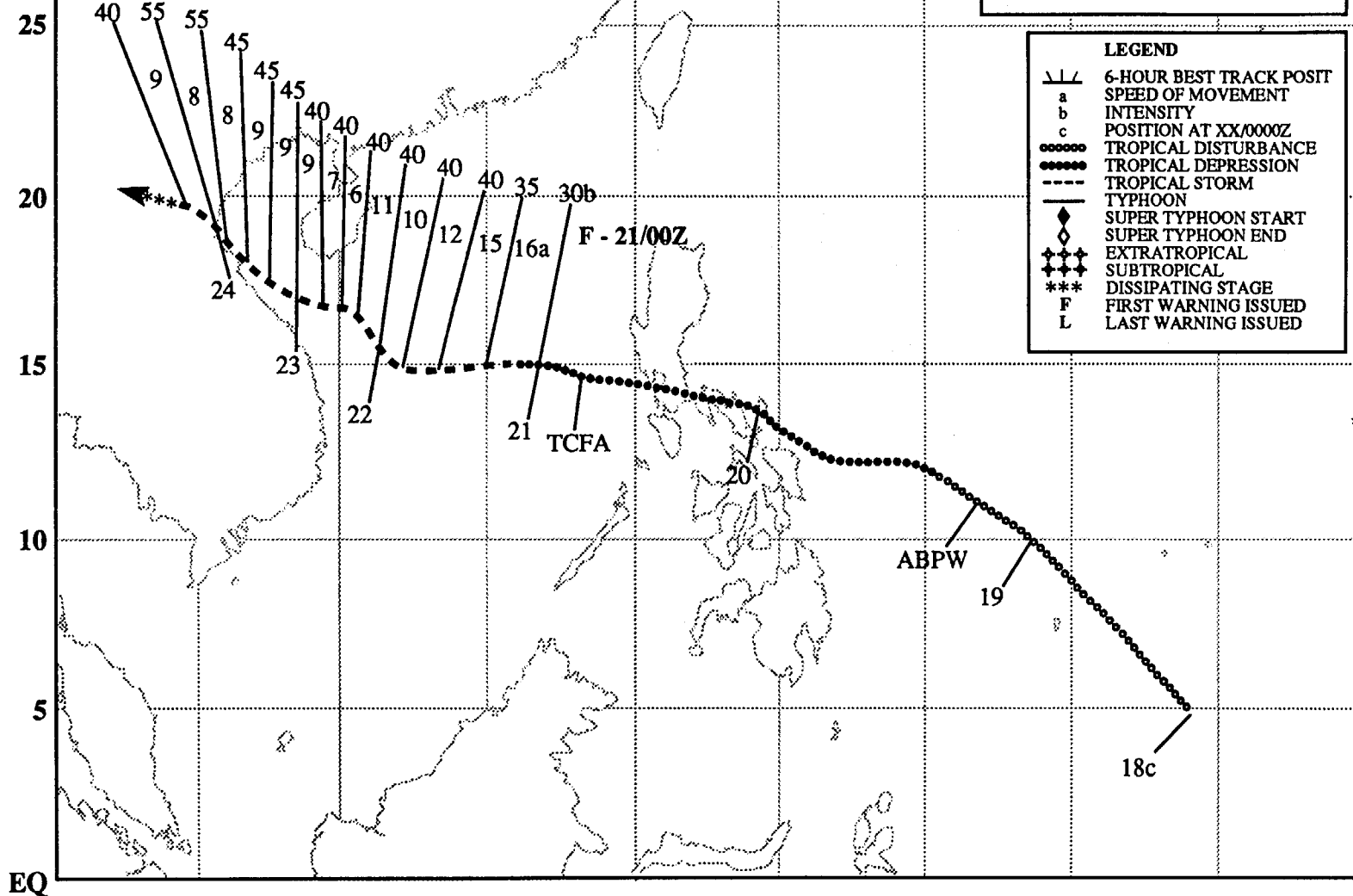
MINIMUM SLP 984MB

L - 24/06Z

F - 21/00Z

LEGEND

- 6-HOUR BEST TRACK POSIT
- a SPEED OF MOVEMENT
- b INTENSITY
- c POSITION AT XX/0000Z
- TROPICAL DISTURBANCE
- TROPICAL DEPRESSION
- TROPICAL STORM
- TYPHOON
- SUPER TYPHOON START
- SUPER TYPHOON END
- EXTRATROPICAL
- SUBTROPICAL
- DISSIPATING STAGE
- F FIRST WARNING ISSUED
- L LAST WARNING ISSUED



TROPICAL STORM IRVING (10W)

Tropical Storm Irving was the fourth tropical cyclone of 1989 to cross the South China Sea and the last to enter the South China Sea until Typhoon Brian (27W) late in September. In August and September the tropical cyclone tracks shifted northward. Irving was short-lived and actually reached its maximum intensity as it made landfall on the coast of northern Vietnam.

As Super Typhoon Gordon (08W) was about to make landfall on the coast of China and Tropical Storm Hope (09W) was reaching peak intensity, the disturbance that would eventually develop into Irving formed on 18 July in the monsoon trough near the southwestern Caroline Islands. The disturbance moved slowly northwestward across the Philippine Sea. Synoptic data at 190000Z July indicated a surface circulation, and the disturbance was

considered a suspect area on that day's Significant Tropical Weather Advisory.

The disturbance crossed the Philippine Sea from southeast of Palau to over the Philippine Islands in three days. The lowest observed minimum sea-level pressure was 1004 mb. Once in the South China Sea, the disturbance became better organized and JTWC issued a Tropical Cyclone Formation Alert at 202000Z. The first warning on Tropical Depression 10W was issued four hours later. The depression was upgraded to tropical storm intensity at 210600Z.

The tropical easterly jet was weakly established across the Southeast Asia; still, the vertical wind shear over the South China Sea due to the northerly flow aloft was sufficient to prevent Tropical Storm Irving (Figure 3-10-1)

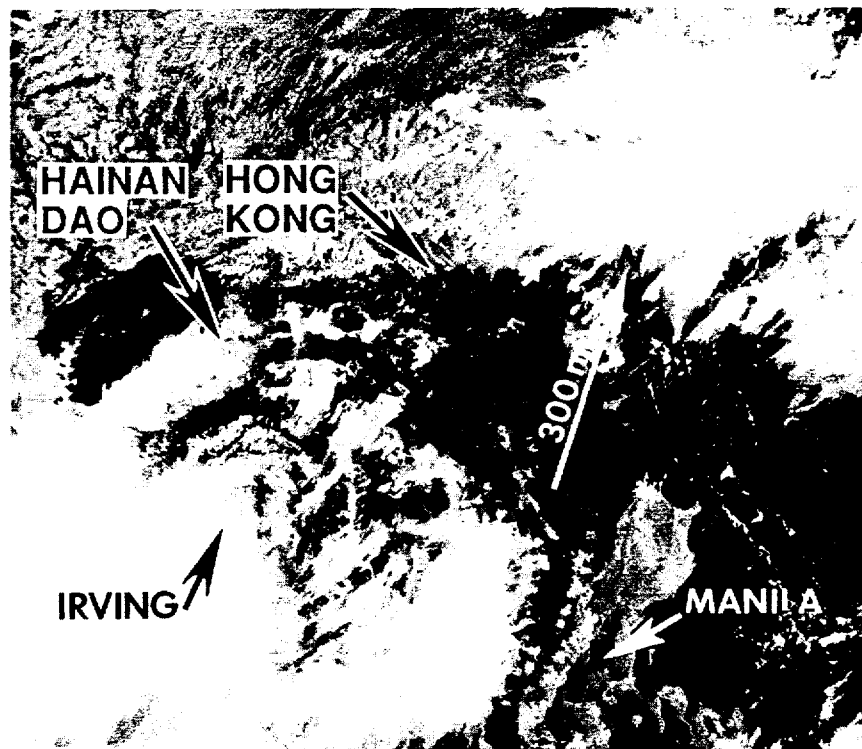


Figure 3-10-1. Vertical wind shear is responsible for the separation between the low-level circulation center and the bright cloud tops to the southwest. The area of cloudiness at the top right of the picture is the remnants of Tropical Storm Hope (09W) over eastern China (NOAA visual imagery 220533Z July).

from reaching typhoon intensity. Throughout Irving's lifetime, the upper-level cloud circulation center was located southwest of the low-level center. As a result, the nighttime infrared satellite fixes of the upper-level cloud features were displaced to the southwest of the low-level circulation center. This tilt to the system also resulted in differences between the radar and corresponding satellite fixes.

Based on satellite imagery, Irving was downgraded to a tropical depression on the 230600Z warning. However, a reanalysis of the imagery indicated Irving actually continued to intensify as it entered the warm waters of the

Gulf of Tonkin. In addition, the Gulf of Tonkin is a natural region of forced low-level convergence due to the surrounding topography. The 240000Z warning upgraded the system again to tropical storm intensity. Irving was downgraded for a second time to a tropical depression on the final warning when it moved into northern Vietnam at 240600Z.

The remnants of Irving moved across the mountains and dissipated over Laos. News reports estimated that at least 102 people died and another 488 were injured in Vietnam. In addition, more than 80,000 houses and 160,000 acres of crops were destroyed.

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E 105 110 115 120 125 130 135 140 145 150 155 E
N 45

TYPHOON JUDY
BEST TRACK TC-11W
20 JUL-29 JUL 89
MAX SFC WIND 95KT
MINIMUM SLP 949MB

40

35

30

25

20

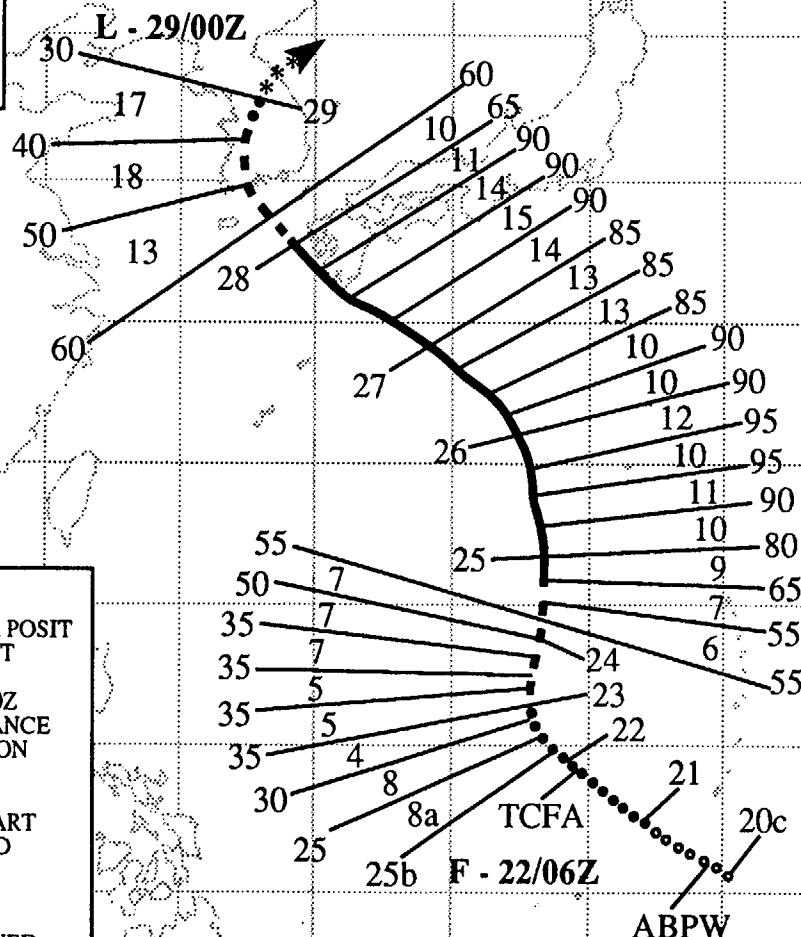
15

10

N 5

LEGEND

\ / \ / 6-HOUR BEST TRACK POSIT
 a SPEED OF MOVEMENT
 b INTENSITY
 c POSITION AT XX/0000Z
 ○ ○ ○ ○ ○ TROPICAL DISTURBANCE
 ● ● ● ● ● TROPICAL DEPRESSION
 - - - - - TROPICAL STORM
 ————— TYPHOON
 ◆ SUPER TYPHOON START
 ◇ SUPER TYPHOON END
 ◆ ◆ ◆ ◆ ◆ EXTRATROPICAL
 ◆ ◆ ◆ ◆ ◆ SUBTROPICAL
 *** DISSIPATING STAGE
 F FIRST WARNING ISSUED
 L LAST WARNING ISSUED



TYPHOON JUDY (11W)

The second of two typhoons to develop during the month of July, Judy formed just west of Guam in the monsoon trough and followed a north oriented track with a critical turn to the northwest, just to the south of Honshu. It crossed the southern coast of Kyushu, made landfall on the south coast of the Korean Peninsula and dissipated rapidly.

As Tropical Storm Hope (09W) weakened over China, two tropical cyclones developed in the monsoon trough which was located near 10° north latitude. First, on July 20, Tropical Storm Irving (10W) developed in the South China Sea. The following day Judy developed 300 nm (555 km) west of Guam. The disturbance that was to become Judy was first mentioned on the Significant Tropical Weather Advisory at 200600Z as a slowly moving tropical disturbance with a poor potential for further development. The potential was upgraded to fair the following day. At 212000Z, JTWC issued a Tropical Cyclone Formation Alert based on synoptic data that

indicated a low-level cyclonic circulation beneath an upper-level anticyclone and satellite imagery that showed increased convection and organization.

As the disturbance's organization and upper-level outflow continued to improve, the first warning followed for Tropical Depression 11W at 220600Z when satellite intensity analysis indicated surface winds of 25 kt (13 m/sec). A cyclonic circulation in the Tropical Upper Tropospheric Trough (TUTT)(Sadler, 1976) to the northwest of the depression provided a source of upper-level divergence needed for further intensification. At 230000Z, the depression was upgraded to tropical storm intensity when satellite analysts estimated 35-kt (18-m/sec) surface winds were present. Judy continued to intensify as the system stayed southeast of the TUTT low, a favorable position for development. At 250600Z, it was again upgraded — this time to a typhoon (Figure 3-11-1). Although most ships avoided Judy's dangerous winds, the moored buoy (WMO

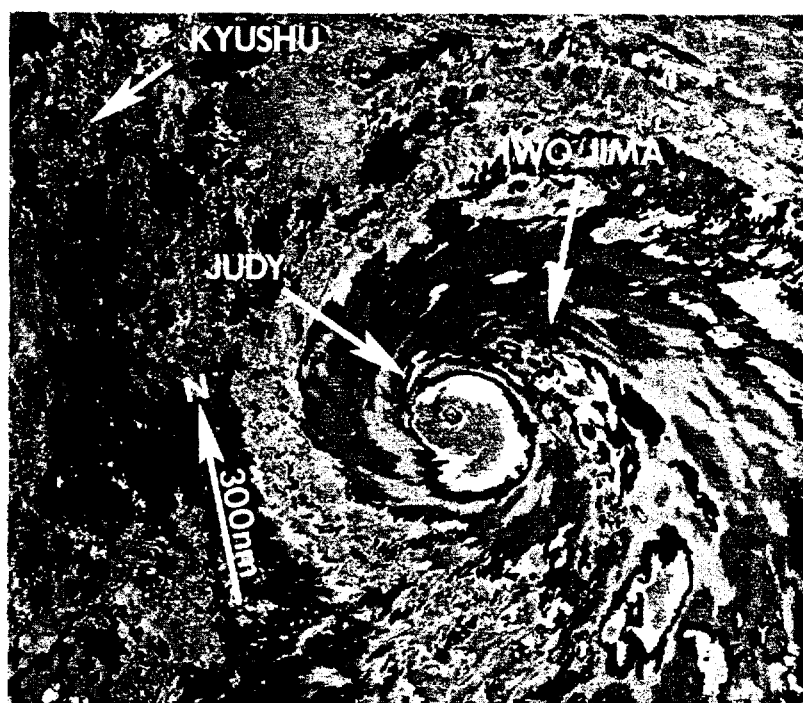


Figure 3-11-1. Judy approaching peak intensity (250945Z July DMSP enhanced infrared imagery).

21004) at 29° north latitude and 135° east longitude provided valuable data to track Judy. Fifty-seven-knot (29 m/sec) winds and a minimum sea-level pressure of 974 mb were recorded as the typhoon passed close by.

Using NOGAPS and satellite data as a guide, JTWc forecast Judy to track northward to Japan and then recurve to the northeast. In contrast, OTCM guidance suggested a northwestward track from the start. When the subtropical ridge did finally build in from the east, OTCM was discounted since all the previous model guidance (Figure 3-11-2)

indicated a northwest track while Judy tracked north. By comparison, Figure 3-11-3 shows JTWc's initial success with the track forecasts. However, after the direction change on 26 July, it took a day for the forecasts to get back on track to the northwest. This situation highlighted the value of the alternate scenario and rapid communications between the customer and the forecaster when forecast difficulties arise.

Judy's interaction with the southern coast of Kyushu at 271800Z resulted in rapid weakening. This trend continued until the

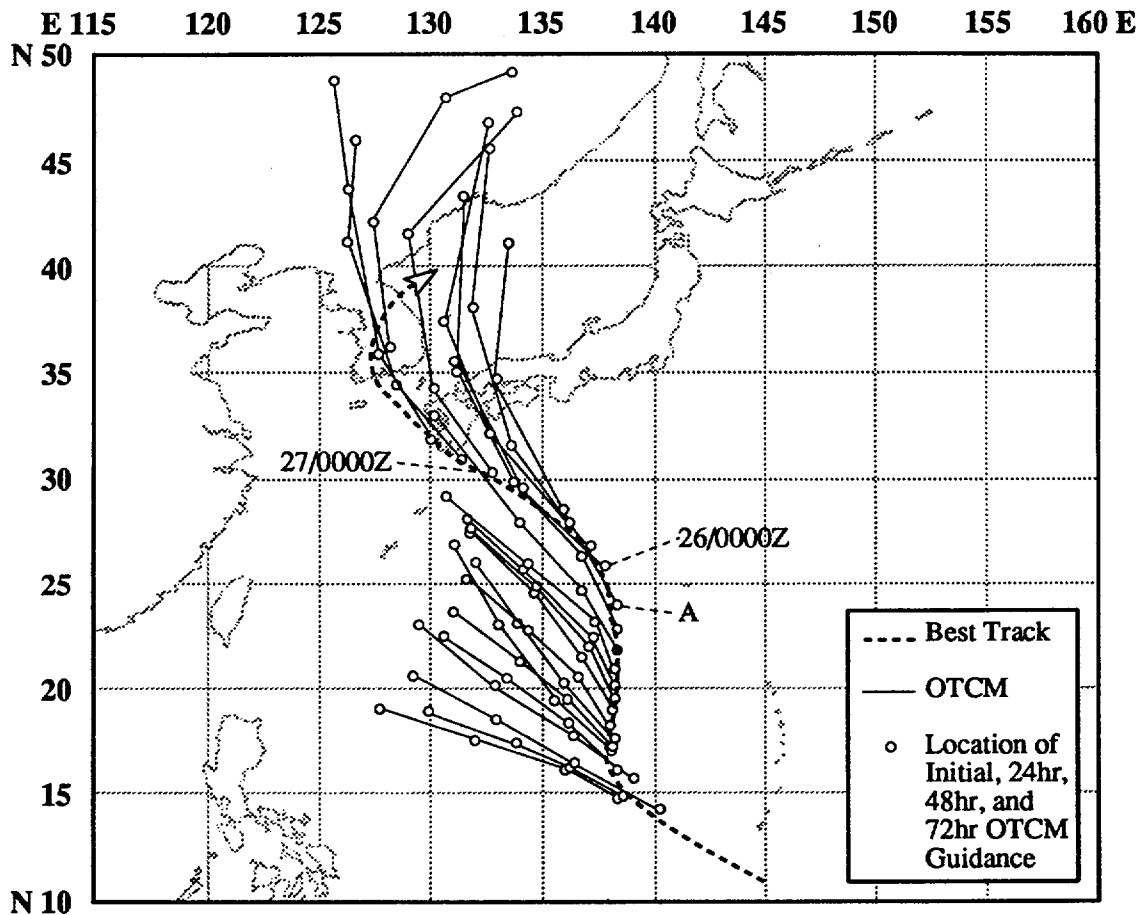


Figure 3-11-2. Comparison of OTCM guidance with the best track. After 251800Z July (point A), the guidance proved correct.

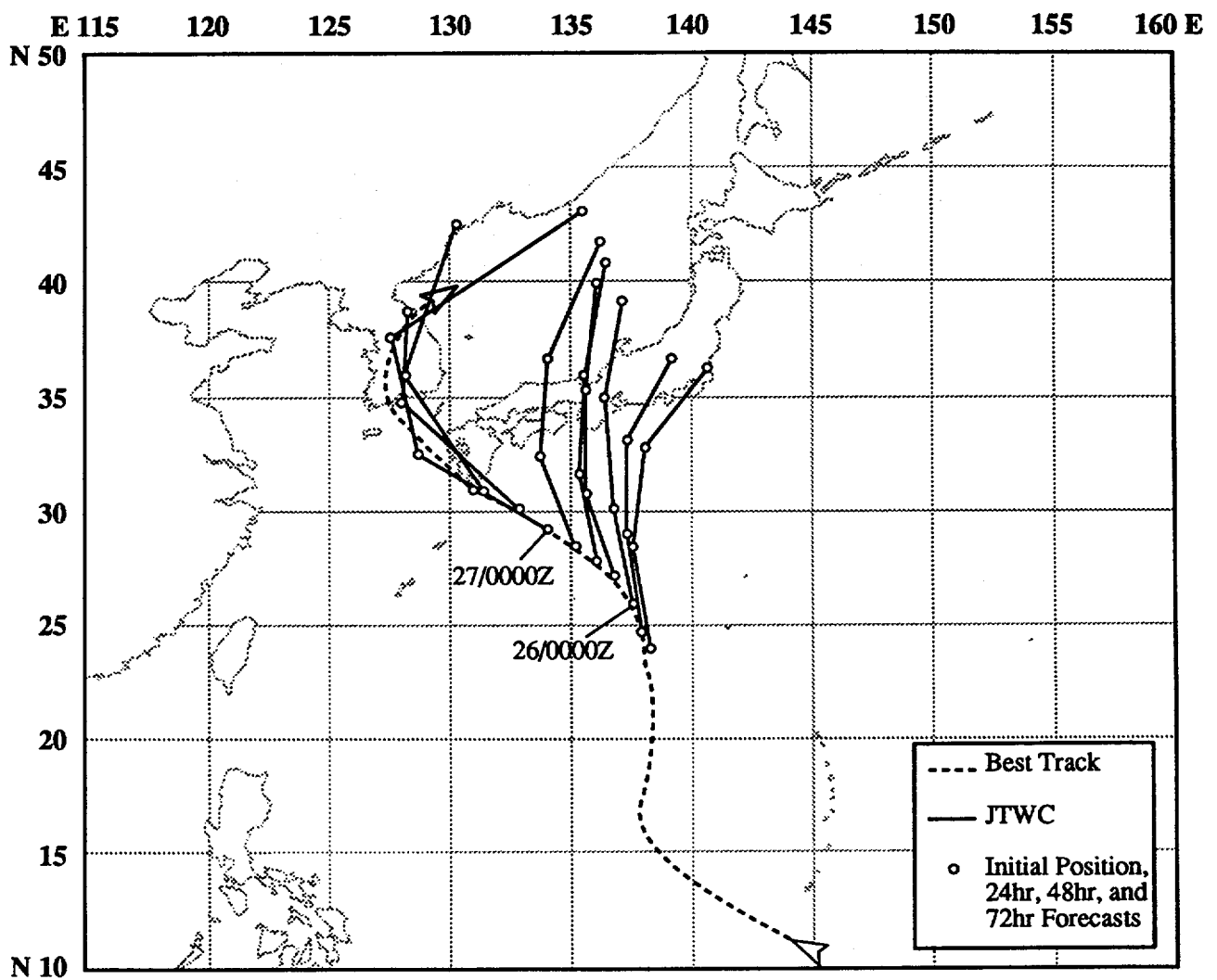


Figure 3-11-3. JTWC forecasts compared with the best track. The major track change to the northwest on 26 July was not reflected in the forecasts until the next day.

tropical cyclone (Figure 3-11-4) made landfall approximately 110 nm (205 km) southwest of Pusan, Korea. By the time Judy reached Osan AB near Seoul, it had weakened significantly. Osan AB (WMO 47122) reported maximum

winds of 22 kt (11 m/sec). At 290000Z, the final warning was issued as the remnants of the system moved towards the Sea of Japan. No reports of damage were received.

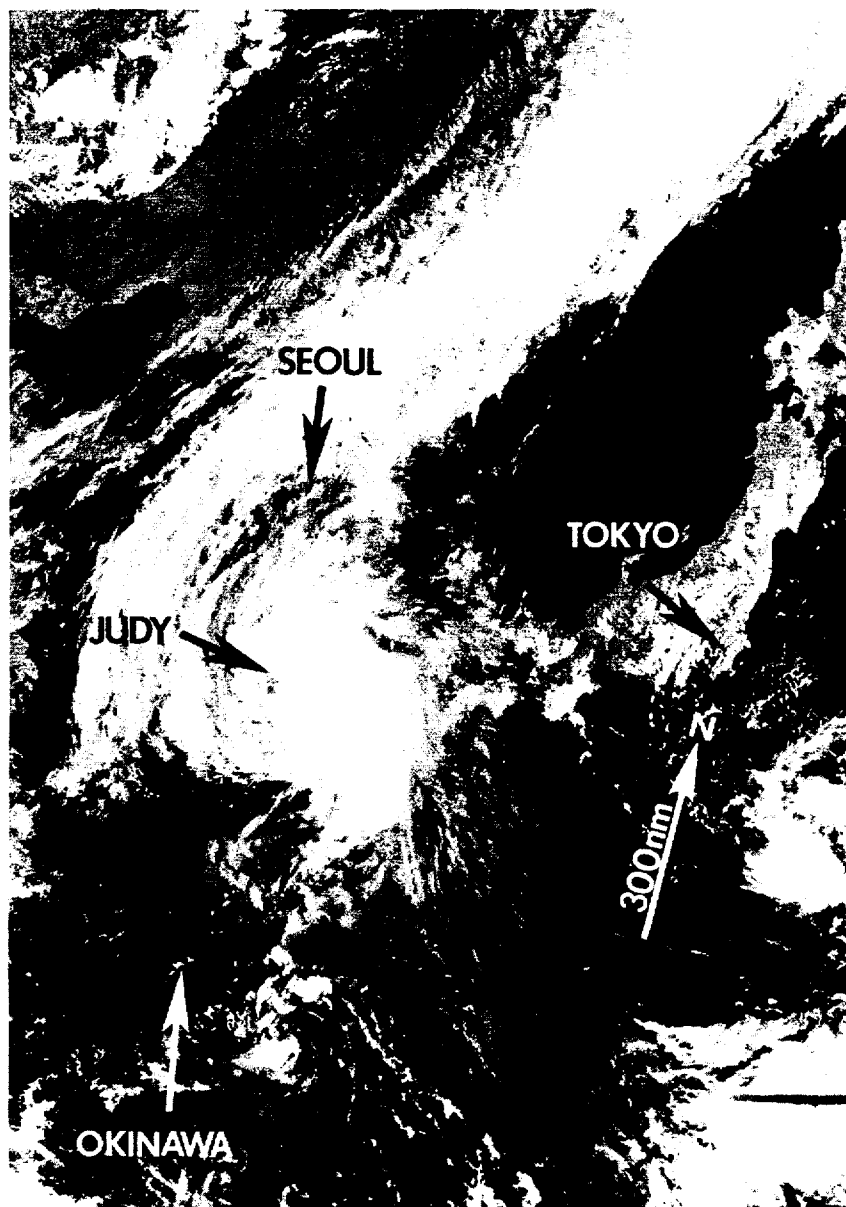
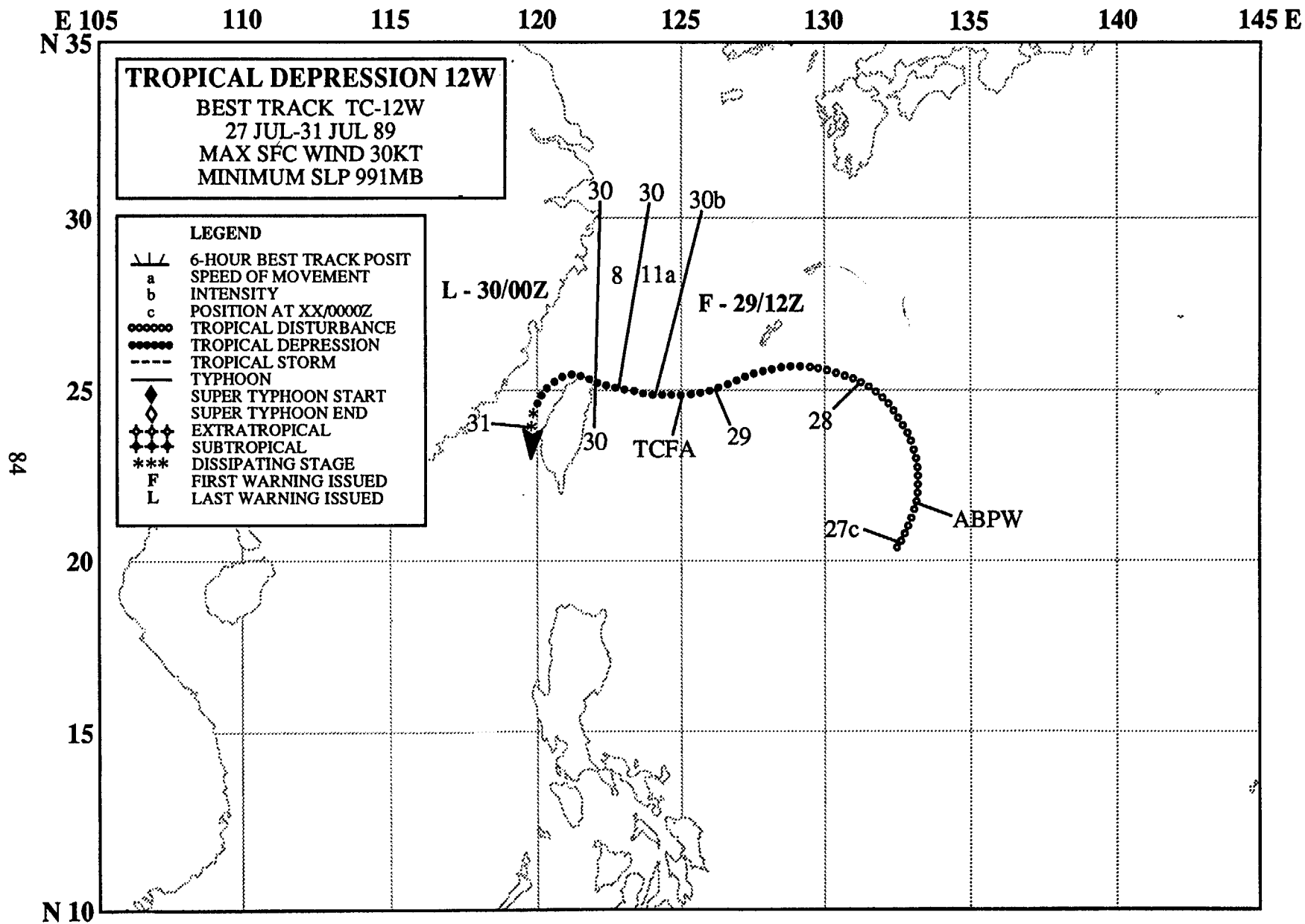


Figure 3-11-4. In the Korea Straits, Judy is about to be downgraded to a tropical storm (280430Z July DMSP visual imagery).

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TROPICAL DEPRESSION 12W

While Typhoon Judy (11W) was tracking northwestward towards Korea, an area of deep convection became persistent to the south-southeast of Judy. This persistent convection, first mentioned in the Significant Tropical Weather Advisory for 27 July, looped around in the monsoon trough and headed west, passing 50 nm (80 km) south of Okinawa at 281200Z. The discovery of a well-developed low-level circulation and falling pressures

prompted the issuance of a Tropical Cyclone Formation Alert at 290630Z, followed by the first Tropical Depression Warning at 291200Z. Because of strong vertical wind shear, the depression was not forecast to intensify to a minimal tropical storm. After the last warning at 300000Z, the deep convection sheared away and continued westward into China while the dissipating low-level circulation tracked southward into the Taiwan Strait.

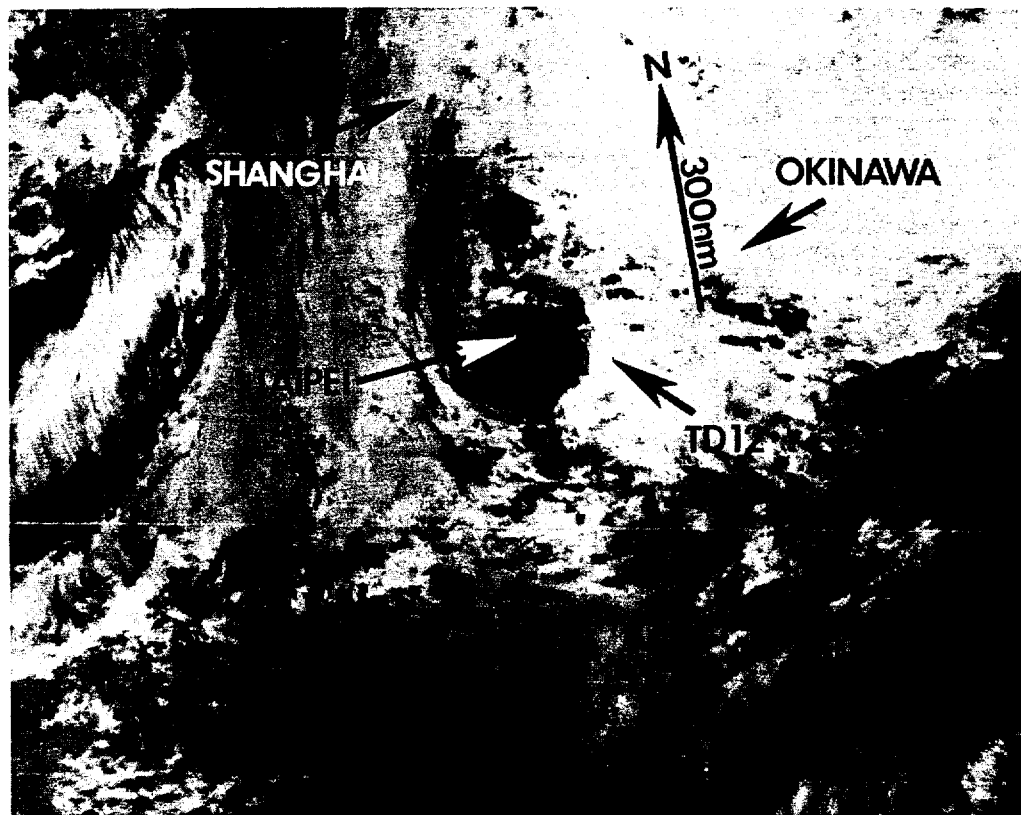
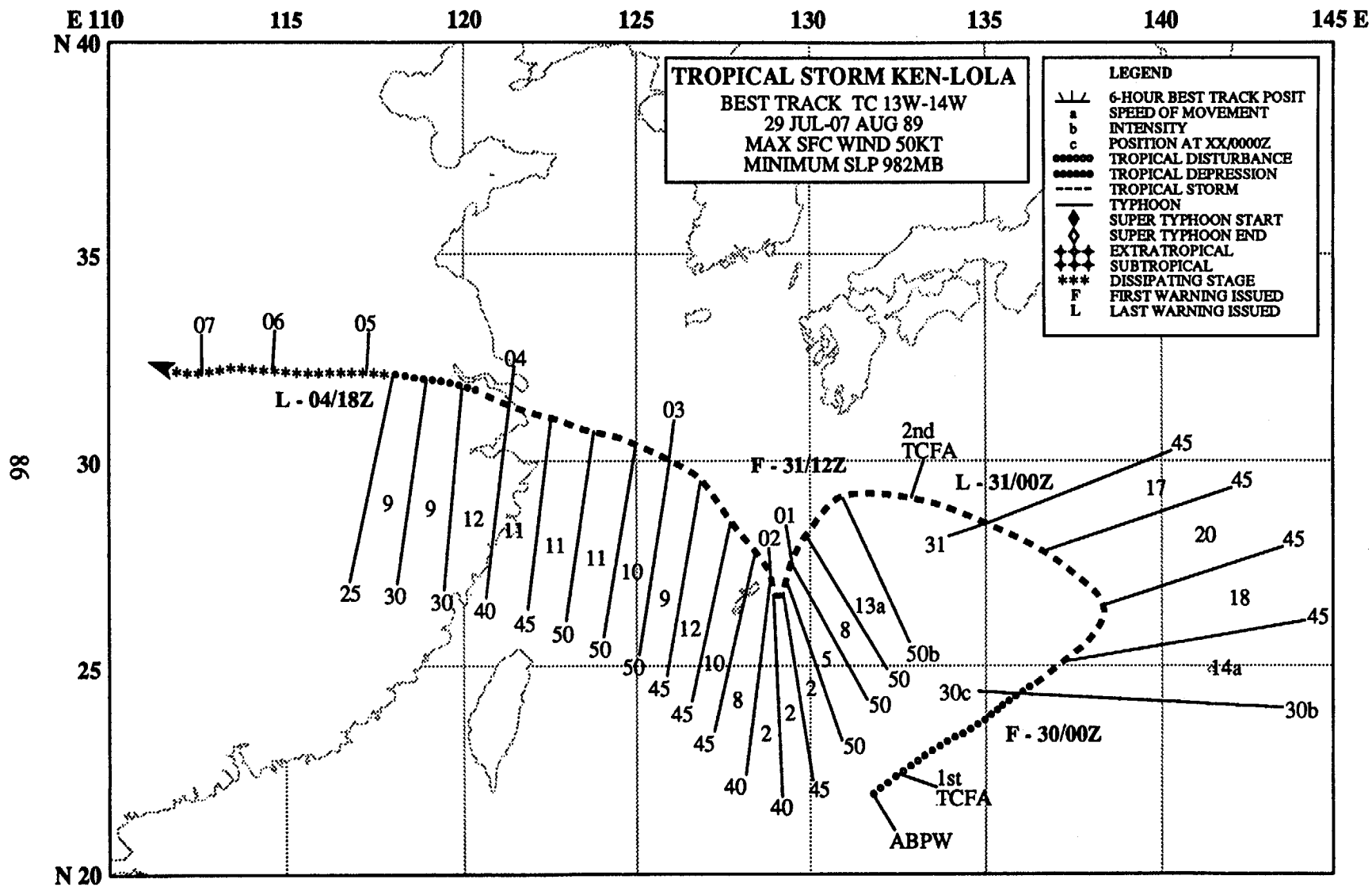


Figure 3-12-1. TD 12W shortly after the first warning (291131Z July DMSP infrared imagery).



TROPICAL STORM KEN-LOLA (13W-14W)

Tropical Storm Ken-Lola underscored the limitations of remote sensing for locating poorly organized systems. Synoptic data proved invaluable in identifying and classifying the system while in warning status and in the post-analysis. While in warning status, JTWC considered the system as two separate tropical cyclones. A detailed post-analysis, even though not absolutely conclusive, strongly suggested that Tropical Storms Ken and Lola were probably the same system. The system generated in the monsoon trough that had already proven itself the most active since July 1973. The system then took an elongated cycloidal track, passing close to Okinawa before making landfall on the coast of eastern China.

In the last week of July, as Tropical Depression 12W tracked through the southern Ryukyu's and Typhoon Judy (11W) dissipated in the Sea of Japan, an active monsoon trough with several small embedded circulation centers extended across Taiwan, eastward to 140° east longitude. A pool of warmer than normal sea surface temperatures engulfed the southern Ryukyu's and extended southeastward to 130° east longitude. On 29 July, synoptic data indicated that a circulation center in the low-level wind field formed over the warm pool about 300 nm (555 km) southeast of Okinawa. While the circulation had a central pressure of 995 mb and winds near the center of only 15 kt (8 m/sec), a broad area of southwesterly monsoonal gales extended 100 to 300 nm (185 to 555 km) south of the center. The first mention of the disturbance appeared on that

day's Significant Tropical Weather Advisory as a suspect area having fair potential for development.

Further evaluation of the 290600Z synoptic data and subsequent satellite imagery led to issuance of a Tropical Cyclone Formation Alert at 290930Z even though the low-level cyclonic circulation center was displaced to the north of the associated convection. Improving organization during the subsequent 18 hours prompted the first warning on Tropical Depression 13W at 300400Z. The depression was forecast to move northward, along the periphery of the monsoon gale area, and loop cyclonically around a mid- to upper-level low located between the depression and Okinawa. This low aloft would restrict the depression's outflow and result in slow development and peaking below typhoon intensity. JTWC correctly forecast the overall character of the track and the limited intensity.

At 300900Z, the second warning valid at 300600Z, was amended to upgrade the depression to Tropical Storm Ken, when synoptic data showed the maximum sustained winds were 45 kt (23 m/sec). For the next 18 hours fixes from (mostly nighttime) satellite imagery indicated continued northeast movement until the final warning was issued at 310000Z. JTWC expected Ken to shear apart and follow the monsoon surge around the northern periphery of an exposed low-level circulation that later would be called Lola. Post-analysis suggests that the 310000Z

position was most likely 250 nm (465 km) northwest of the warning position (Figure 3-13-1) and that the low-level system had moved northwestward since 301200Z.

At 310600Z, JTWC issued a Tropical Cyclone Formation Alert for a disturbance located about 300 nm (555 km) northeast of Okinawa. The satellite imagery (Figure 3-13-2) indicated an exposed low-level center with increasing convection to the south. This system now had gales extending several hundred miles north of the center. At 311030Z, an abbreviated

warning on Tropical Storm Lola was issued after the **USS Dubuque** (LPD8) reported sustained winds of 50 kt (26 m/sec) at 310300Z followed by 40 kt (21 m/sec) and falling surface pressure three hours later. Also, at 0600Z, another ship (call sign 9MTS) reported westerly winds approximately 90 nm (165 km) south of the **USS Dubuque**. These data demonstrated that the winds reported by the Dubuque were associated with a circulation center and not the tight pressure gradient near Japan (Figure 3-13-3), as initially thought.

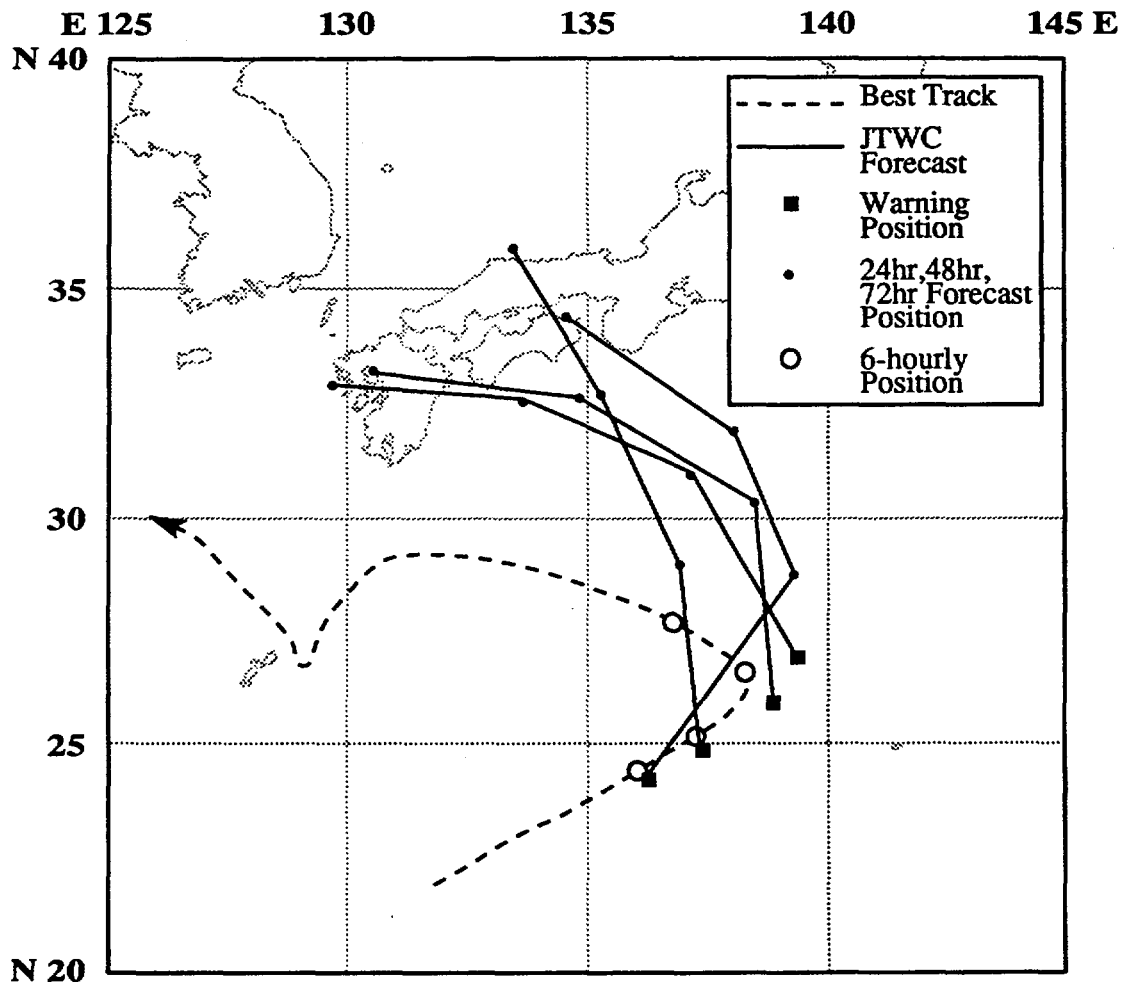
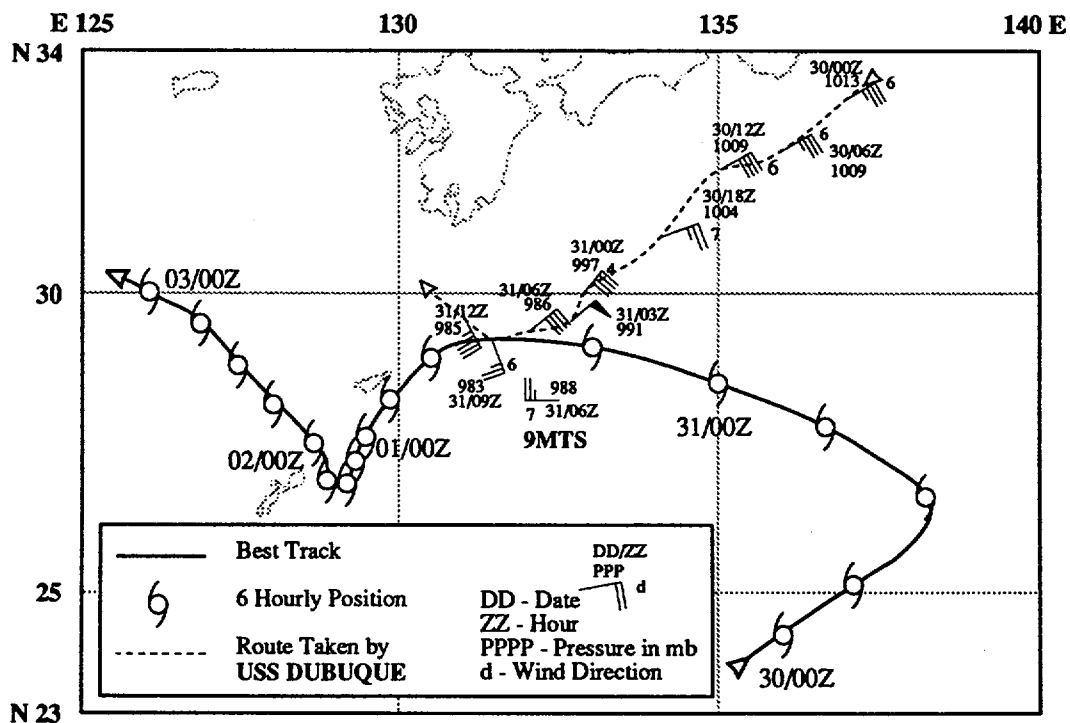
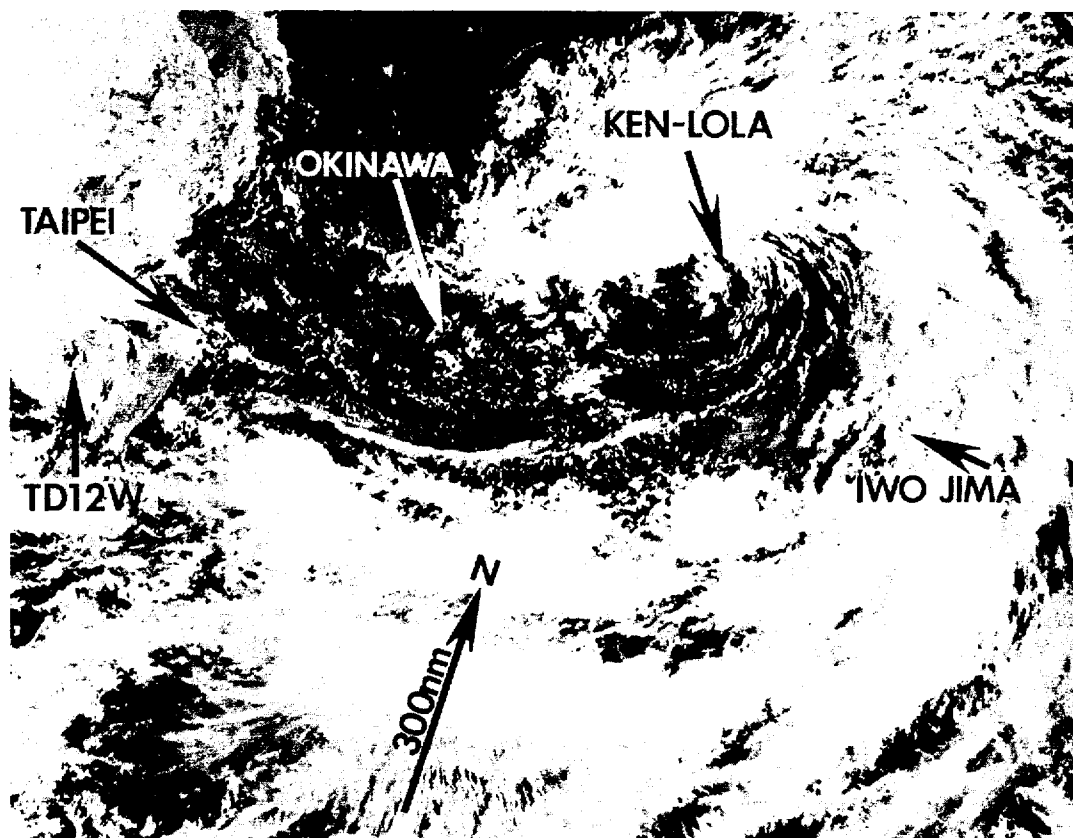


Figure 3-13-1. Ken's expected track verses the best track.



The first 72-hour forecast for Lola followed at 311200Z. The problems that aggravated this initial warning were the inconsistencies between fix platforms. Radar fixes were displaced to the west of the satellite fixes and suggested the system was moving rapidly southwestward. In contrast, the satellite fixes, based on cold cloud tops on infrared imagery, implied slow westward movement. Based on the prevailing northeasterly steering flow, the system was forecast to track west-southwestward and pass about 100 nm (185 km) northwest of Okinawa.

In a short time an understanding of the track became clearer. The radars were tracking a band of convection that was spiraling around the mid-level low. Also, the pressure at Kadena AB (WMO 47931) on Okinawa was not falling

rapidly indicating Lola probably was not tracking rapidly to the southwest as had been suggested by the radar fixes. As a consequence, JTWC slowed the forecast speed of movement and angled the track towards Taiwan.

The mid-level cyclone appears to have been the major influence on Ken-Lola's track (Figure 3-13-4). In fact Ken-Lola's path described a elongated cycloid with the storm representing a point on the rotating "rim" of the westward moving 500 mb "wheel". The track made a cusp near Okinawa as the 500 mb center passed to the west of the system. The mid-level low pulled Ken-Lola northward and then westward into the East China Sea.

Kadena AB (WMO 47931) recorded peak winds of 30 kt (15 m/sec) as the system

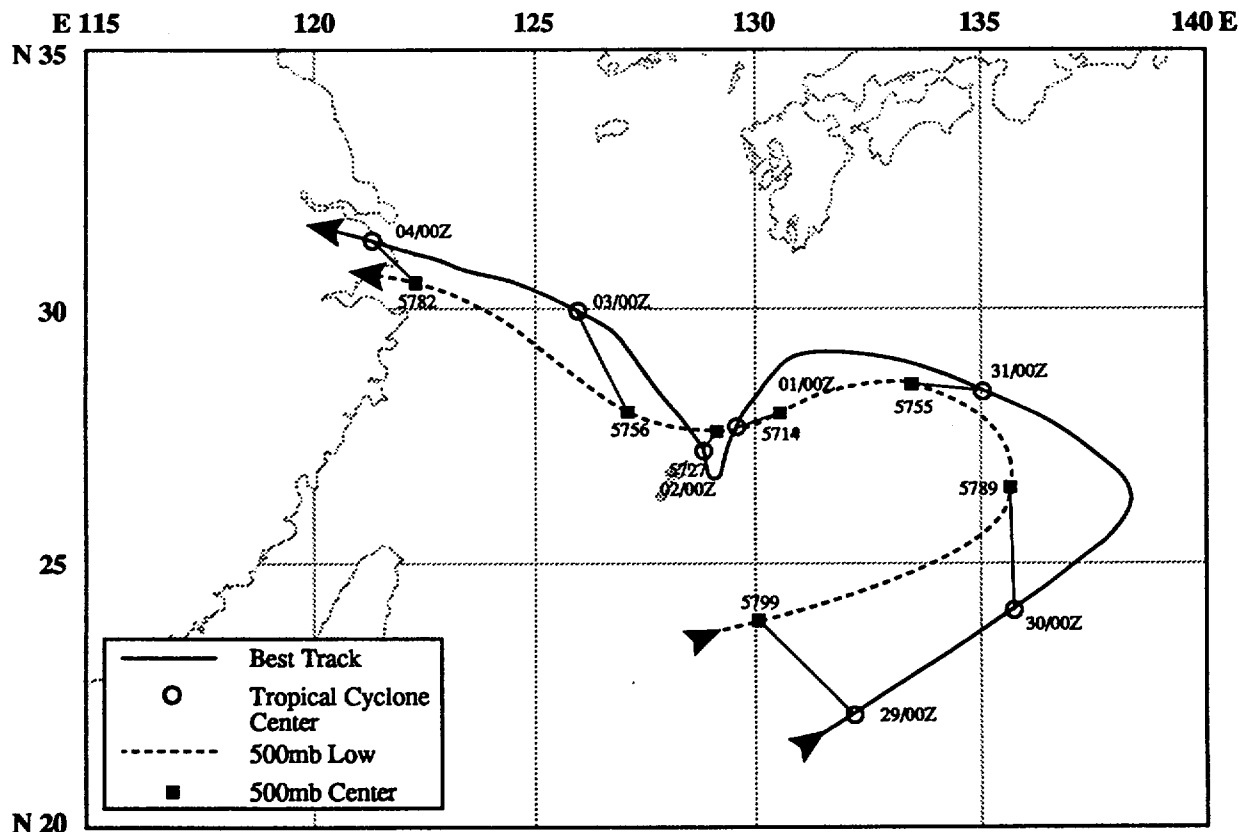


Figure 3-13-4. Spatial relationship between the tropical cyclone and accompanying 500 mb circulation center. Minimum 500 mb heights are in meters. Positions are for 0000Z from 29 July through 4 August.

passed within 80 nm (150 km) between 011800Z and 020000Z (Figure 3-13-5). The USS Dubuque (LPD 8), which remained near Okinawa, reported 35-kt (18- m/sec) winds at 020600Z that decreased to 24 kt (12 m/sec) by 021200Z.

On 3 August, a building ridge over Manchuria caused Ken-Lola to take a more westward track toward Shanghai. Due to

concern that a trough, approaching eastern China could reverse the tropical cyclone's track and take it northeastward into the Yellow Sea and Korea, the warnings continued until 041800Z when it was more than 250 nm (465 km) inland. The low relief and wetlands of the Yangtze River Valley allowed the weak circulation to maintain itself inland for several days. No reports of damage were received.

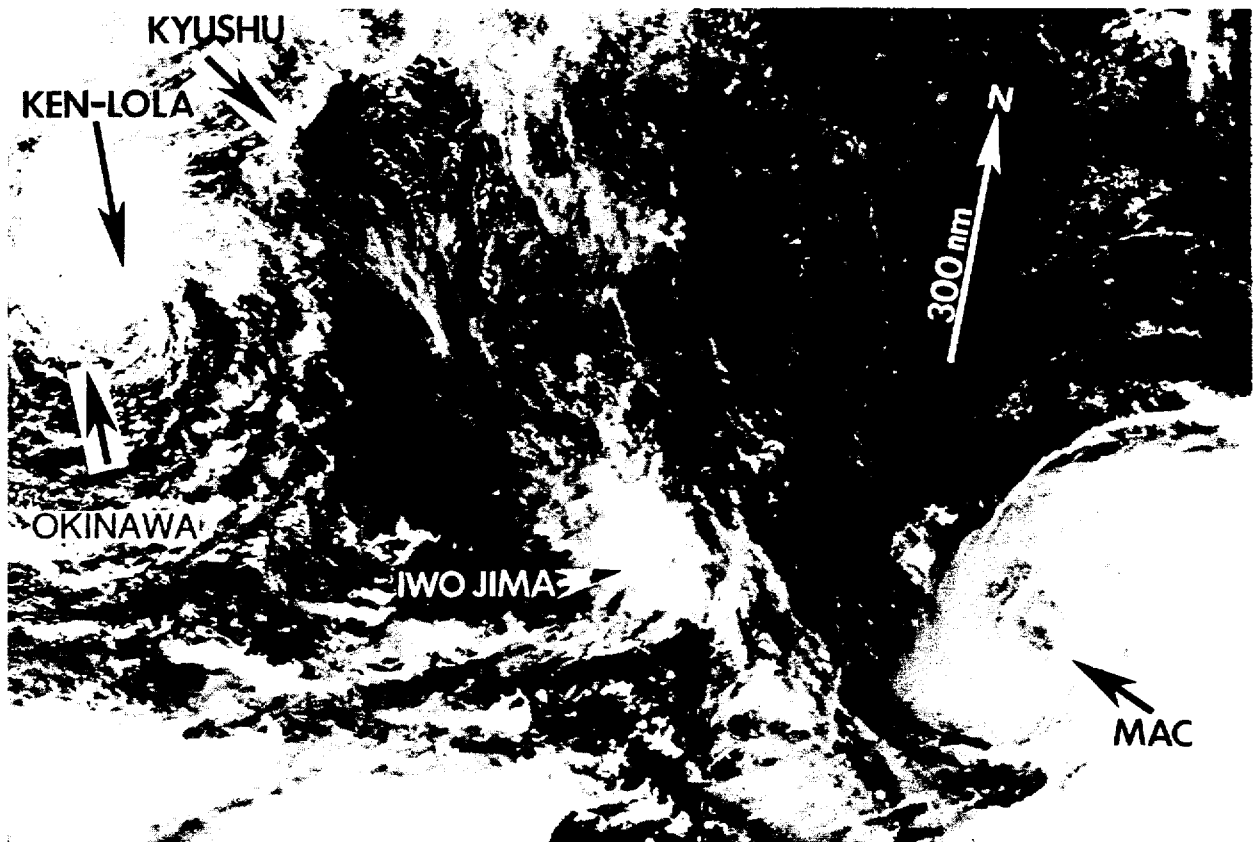
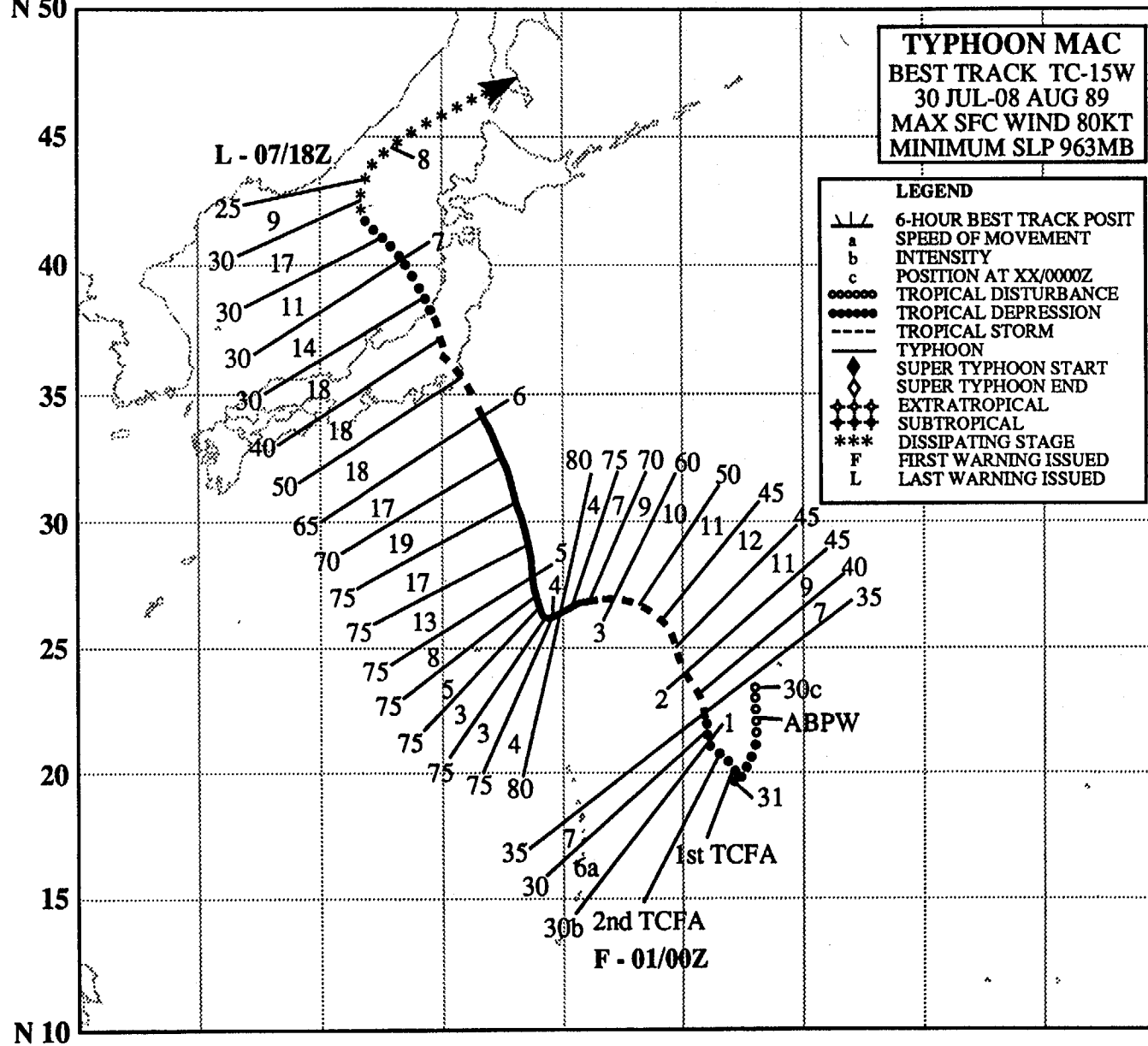


Figure 3-13-5. Ken-Lola nears Okinawa. Typhoon Mac (15W) is at the lower right (012344Z August DMSP visual imagery).



TYPHOON MAC (15W)

The first typhoon of August, Mac developed at a higher than average latitude. Its track and intensity were influenced by a complex mid-latitude synoptic regime and complicated by a multi-storm environment. JTWC and NOGAPS had considerable difficulty distinguishing between short-term and long-term trends. Developing northeast of the Mariana Islands, Mac began with a general northwest track, moved westward 48 hours, then accelerated on a northwestward track and made landfall northeast of Tokyo. Mac weakened rapidly as it moved into and across the Sea of Japan, and finally dissipated over southern Sakhalin Island.

As the most active July since 1973 came to a close, Typhoon Judy (11W) was dissipating over Korea and Tropical Storm Ken-Lola (13W) was threatening Okinawa. At the same time, an

area of convection developed approximately 600 nm (1111 km) northeast of Saipan in an extremely active monsoon trough that extended as far east as Wake Island. The 300000Z July surface analysis indicated that a low-level cyclonic circulation with a 1008 mb pressure was associated with an area of disturbed weather. JTWC classified the disturbance as having poor potential for further development on the 300600Z Significant Tropical Weather Advisory. Subsequent synoptic reports indicated that the central pressure had decreased to 1006 mb and surface winds had increased. Thus, JTWC reissued the Significant Tropical Weather Advisory at 301000Z to upgrade the disturbance's potential to fair.

The disturbance's central convection increased and additional synoptic reports indicated that the central pressure had fallen to

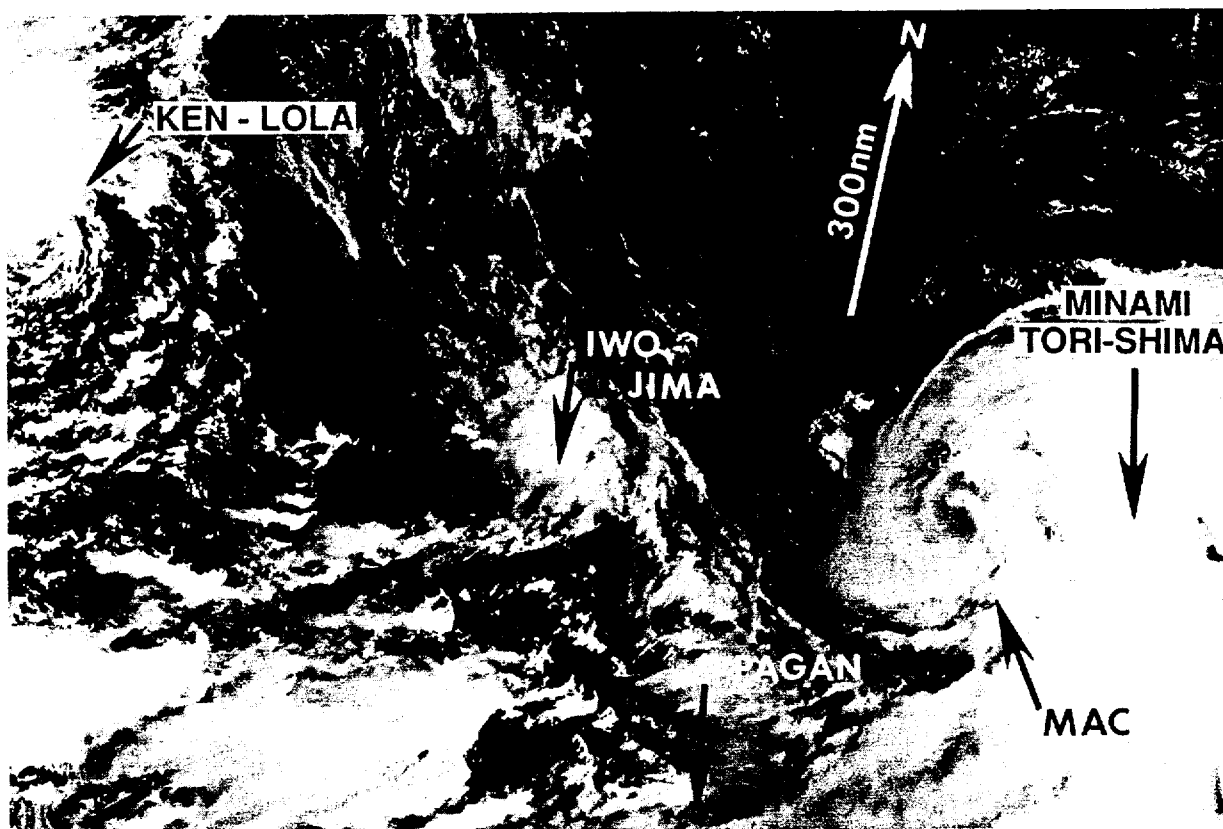


Figure 3-15-1. Mac's cirrus outflow (at left) is impressive compared to Ken-Lola (13W-14W) (012344Z August DMSP visual imagery).

1000 mb. The surface winds north of the system were 20 to 25 kt (10 to 13 m/sec) and monsoon gales were present to the south. JTWC issued a Tropical Cyclone Formation Alert at 310400Z with the disturbance moving to the southeast. Subsequent fix information indicated that the disturbance had actually made a cyclonic loop and was moving northwestward out of the Alert area. In response, JTWC reissued the Alert at 311700Z.

While the first warning on Tropical Storm Mac was issued at 010000Z August, post-analysis indicated that the system did not reach tropical storm intensity until 12 hours

later. The first series of forecasts called for Mac to track northward along the 150° east meridian. Due to the mid-tropospheric subtropical high weakening, the early stages of the forecasts verified well — as Mac tracked north-northwestward for the next 36 hours.

While Tropical Storm Ken-Lola (13W-14W) was in the vicinity of Okinawa on 2 August, JTWC changed its forecast outlook on Mac (Figure 3-15-1). The 020600Z warning had Mac moving westward along 30° north latitude in the 48- to 72-hour period as a complex series of events began to unfold. At the same time as a long-wave trough moved

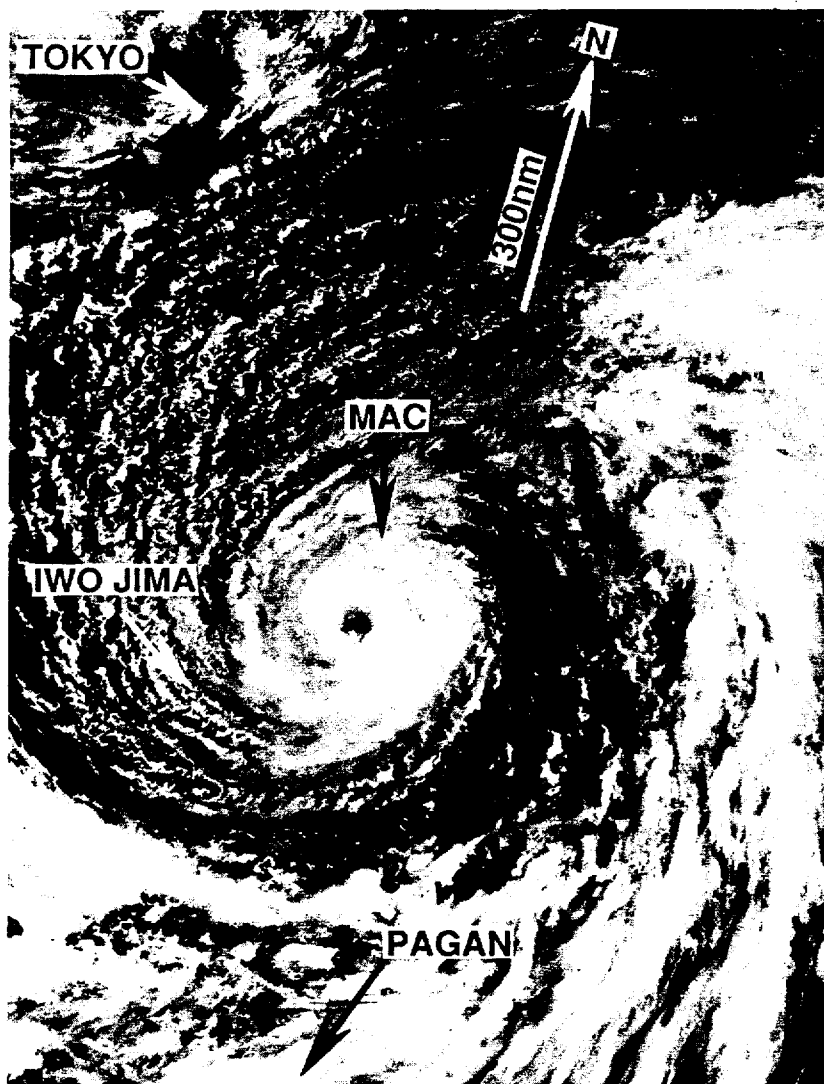


Figure 3-15-2. At peak intensity, Mac is surrounded by a ring of subsidence (032304Z August DMSP visual imagery).

eastward into the Sea of Japan, a large TUTT cyclone began to tumble rapidly westward from the date line. While the TUTT cell moved northwest of Mac, the mid-tropospheric subtropical ridge strengthened, placing Mac under the influence of easterly flow. This was similar to events that had recently forced Typhoon Judy (11W) to move westward. JTWC would remain with the westward track along 30° north latitude for the next nine warnings.

The westward movement began much earlier than forecast, in fact, along 27° instead of 30° north latitude and within 12 hours instead of 48 hours. Mac continued the westward movement for the next 48 hours reaching typhoon intensity at 030300Z. JTWC had high confidence in its forecast as NOGAPS built a high over the Sea of Japan and most of the objective techniques supported slow westward movement. Confidence was further heightened when Mac began tracking west-southwestward at 030000Z. JTWC forecasters recognized the unfavorable upper-level regime and displayed great success with the intensity forecasts. Mac reached its peak intensity of 80 kt (41 m/sec) at 031800Z (Figure 3-15-2).

During its westward track, an ominous slowing of Mac's forward speed occurred. At 040600Z Mac was moving very slowly west-southwestward. The 040000Z analysis indicated that a jet maximum approaching the trough axis which could deepen the trough. The Prognostic Reasoning accompanying the 040600Z warning did mention recurvature as a low-probability alternate scenario. JTWC's westward scenario was reinforced by the movement of a high from Mongolia to coastal Manchuria. Forecasters thought the continued eastward movement of that high and Mac's westward movement would allow the typhoon to escape the influence of the digging trough as ridging reestablished itself to Mac's north.

In the meantime, the TUTT cell that had tumbled westward slowed down and linked up with the mid-latitude trough in the Sea of Japan. This blocked significant eastward movement of the high over Manchuria and changed Mac's steering flow from westward to northward around the east side of the TUTT cell. JTWC added northward movement to the Prognostic Reasoning accompanying that 041200Z warning as a moderate probability alternate scenario. At 041800Z, the westward forecast was abandoned as Mac made a slow move northward and the new 041200Z NOGAPS no longer showed the high building over the Sea of Japan. JTWC swung the forecast track to the northwest toward Osaka near the 72-hour point. JTWC remained with that forecast for the next two warnings.

Meanwhile Mac had accelerated from 3 kt (6 km/hr) at 041200Z to 13 kt (24 km/hr) toward the north-northwest at 050600Z as it ran along the east side of the TUTT cell. The TUTT cell was expected to resume its normal southwestward movement causing Mac to resume a northwestward track toward Osaka. This reasoning was reinforced by height falls occurring *west* of Tokyo.

By 051200Z, Mac had accelerated to 17 kt (32 km/hr). At this time, JTWC shifted the forecast track to pass 180 nm (335 km) *east* of Tokyo within 24 hours. Satellite fixes indicated a northward movement and subsequent radar observations from Tori-Shima (WMO 47639) confirmed the north-northwestward track. In addition, the TUTT cell and an upper-level low over the northern Sea of Japan linked producing an extended trough. Mac would now maintain a forward speed of 17 kt (32 km/hr), or more, during the next 30 hours.

After 051800Z, Mac shifted from a north-northwestward course to a more north-westward course, as the trough in the Sea of

Japan began to weaken. Mac finally passed *east* of Tokyo at 060700Z, but only by 60 nm (111 km) with an intensity of 45 kt (23 m/sec) (Figure 3-15-3). The tropical cyclone made landfall at 061000Z. At 061200Z, Mac was downgraded to tropical storm intensity, however, post-analysis indicates Mac was a tropical storm at least six hours earlier.

Mac weakened while crossing Japan, but without the benefit of satellite intensity analysis and availability of continuous observations, JTWC conservatively maintained Mac at tropical storm intensity until 070600Z. MAC actually entered the Sea of Japan, near Sakata, as a tropical depression at 061700Z. The final warning on Tropical Depression 15W was issued at 071800Z. The remnants turned northeastward and dissipated over southern Sakhalin island on 8 August.

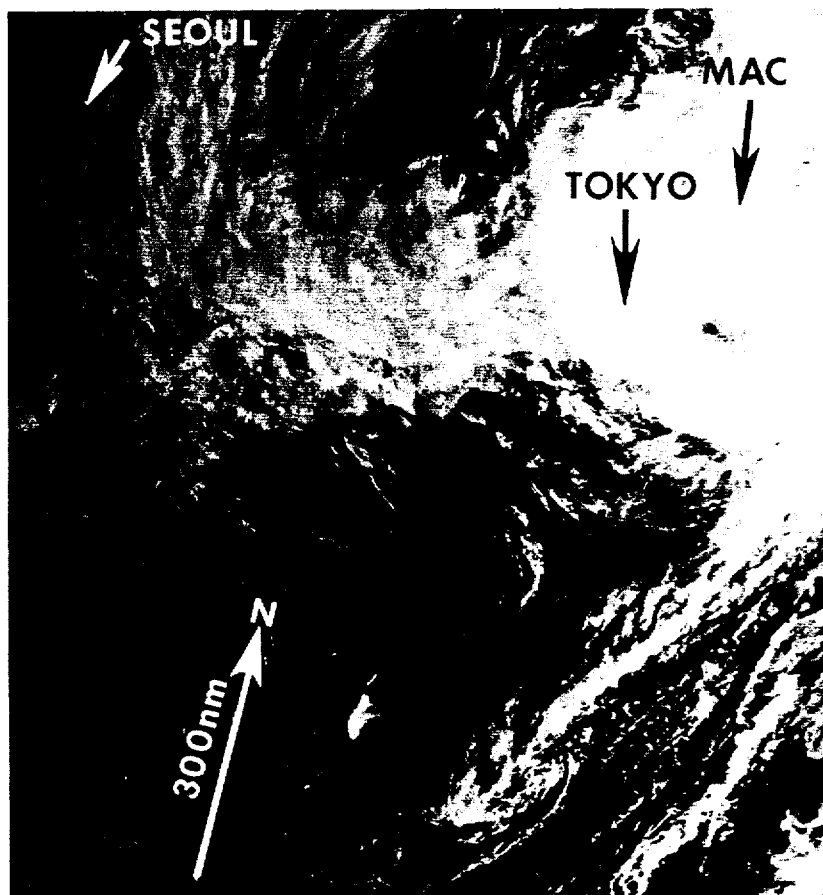


Figure 3-15-3. Mac approaches Japan (060438Z August NOAA visual imagery).

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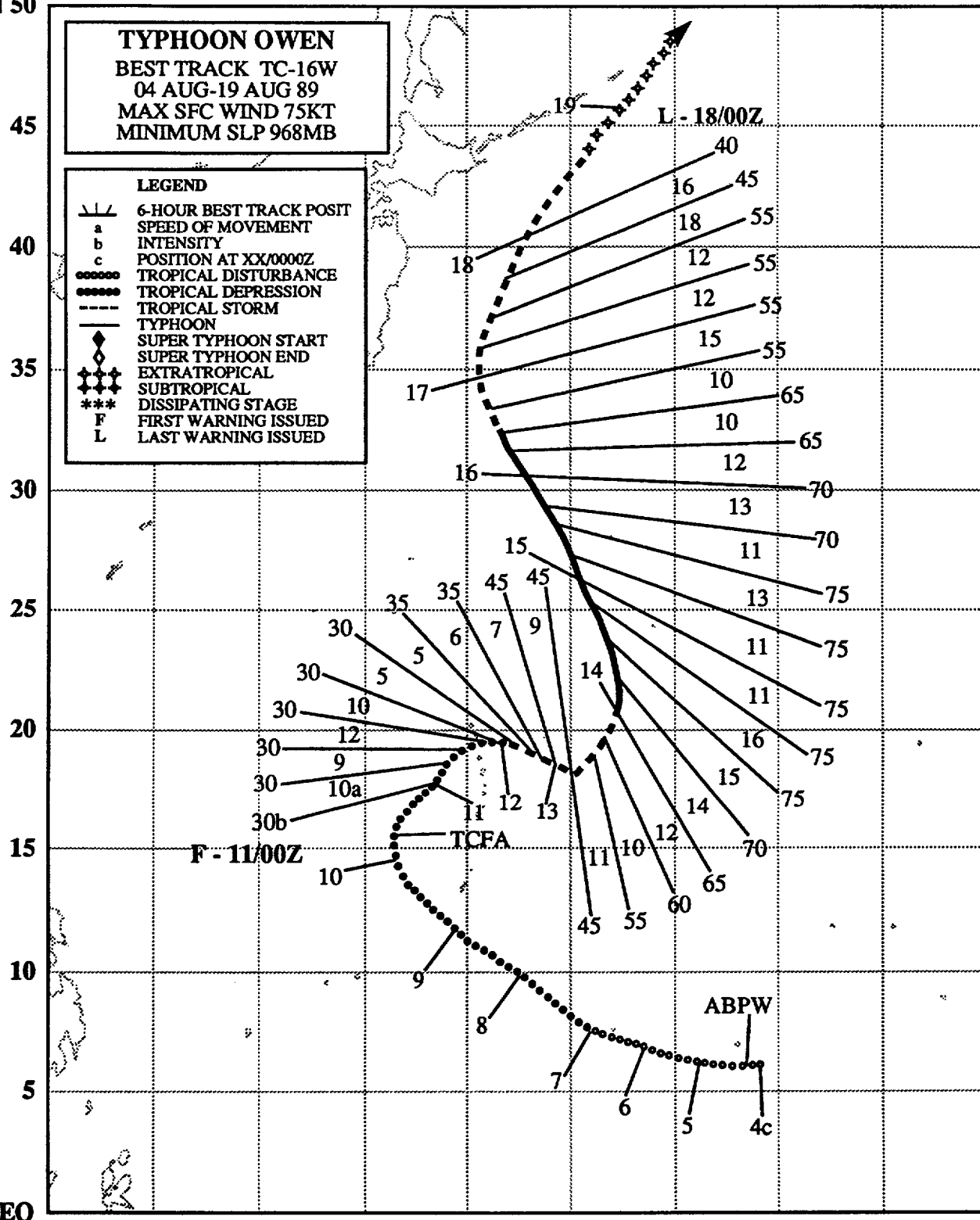
E 125 130 135 140 145 150 155 160 165 170 E

N 50

TYPHOON OWEN
 BEST TRACK TC-16W
 04 AUG-19 AUG 89
 MAX SFC WIND 75KT
 MINIMUM SLP 968MB

LEGEND

\ / \ / 6-HOUR BEST TRACK POSIT
 a b c SPEED OF MOVEMENT
 INTENSITY
 ○ ○ ○ ○ ○ ○ TROPICAL DISTURBANCE
 ● ● ● ● ● ● TROPICAL DEPRESSION
 - - - - - TROPICAL STORM
 ————— TYPHOON
 ◆ SUPER TYPHOON START
 ◇ SUPER TYPHOON END
 + + + + + EXTRATROPICAL
 * * * * * DISSIPATING STAGE
 F FIRST WARNING ISSUED
 L LAST WARNING ISSUED



TYPHOON OWEN (16W)

Typhoon Owen generated in the monsoon trough and intensified slowly while moving on a general northwest to northward track. Due to the proximity* of Typhoon Nancy (17W) to the east, Owen took more than a week to reach tropical storm intensity. Later, its binary interaction with Typhoon Nancy (17W) resulted in an unusual southeastward track during its developing stage. Then, the tropical cyclone followed Nancy (17W) through recurvature, extratropical transition and into high latitudes.

The initial disturbance that spawned Typhoon Owen began as an area of convection in the monsoon trough south of Pohnpei in the eastern Caroline Islands. After the convection persisted for 24 hours, JTWC included the disturbance as a suspect area on the Significant Tropical Weather Advisory at 040600Z. Synoptic data indicated a weak low-level circulation under easterly flow aloft. During the next six days, the amount and organization of the convection associated with the disturbance fluctuated as the monsoon trough repositioned further north. Finally convection consolidated beneath an upper-level anticyclone, prompting JTWC to issue a Tropical Cyclone Formation Alert at 100600Z.

During the next 18 hours, the system continued to organize, although its upper-level outflow was restricted by a TUTT cell centered four to five degrees latitude to the north-northwest. At 110000Z, JTWC issued a 36 hour tropical depression warning on Tropical Depression 16W and forecast no intensification because of its proximity to the TUTT cell. The tropical cyclone tracked northeastward along the monsoon trough axis and through the northern Mariana Islands for the next 18 hours, influenced both by the TUTT cell and by Tropical Depression 17W. By 120000Z, a well-defined upper-level anticyclone had established itself over Owen, and the system improved its organization and convection. Anticipating further intensification, JTWC transitioned to a regular 72-hour warning. At 121200Z, the depression reached tropical storm intensity based on satellite intensity estimates. By this time, a binary interaction with Nancy (17W) was beginning to influence Owen's track and resulting in a slow southeastward movement until 131200Z. (For specific diagrams of this binary interaction, please see the following article on Typhoon Nancy (17W). Owen became a typhoon at 131800Z and reached its peak intensity of 75 kt (38 m/sec) at 141200Z.

* If formative tropical cyclones are separated by distances of less than fifteen degrees, interaction (at the expense of one, or the other) between the two circulations is often observed.

As Owen followed Nancy (17W) to the north-northwest, the recently formed eye began to fill (Figure 3-16-1). With the subtropical ridge close by, at 161500Z, Owen weakened to tropical storm intensity and began to be buffeted by upper-level westerly flow. Twelve hours later Owen recurved around the ridge and

accelerated to the northeast. At 180000Z, JTWC issued its final warning on Owen as it crossed 40° north latitude and was becoming extratropical. During its lifetime, Owen was a threat primarily to maritime interests. No reports of damage or loss of life were received.

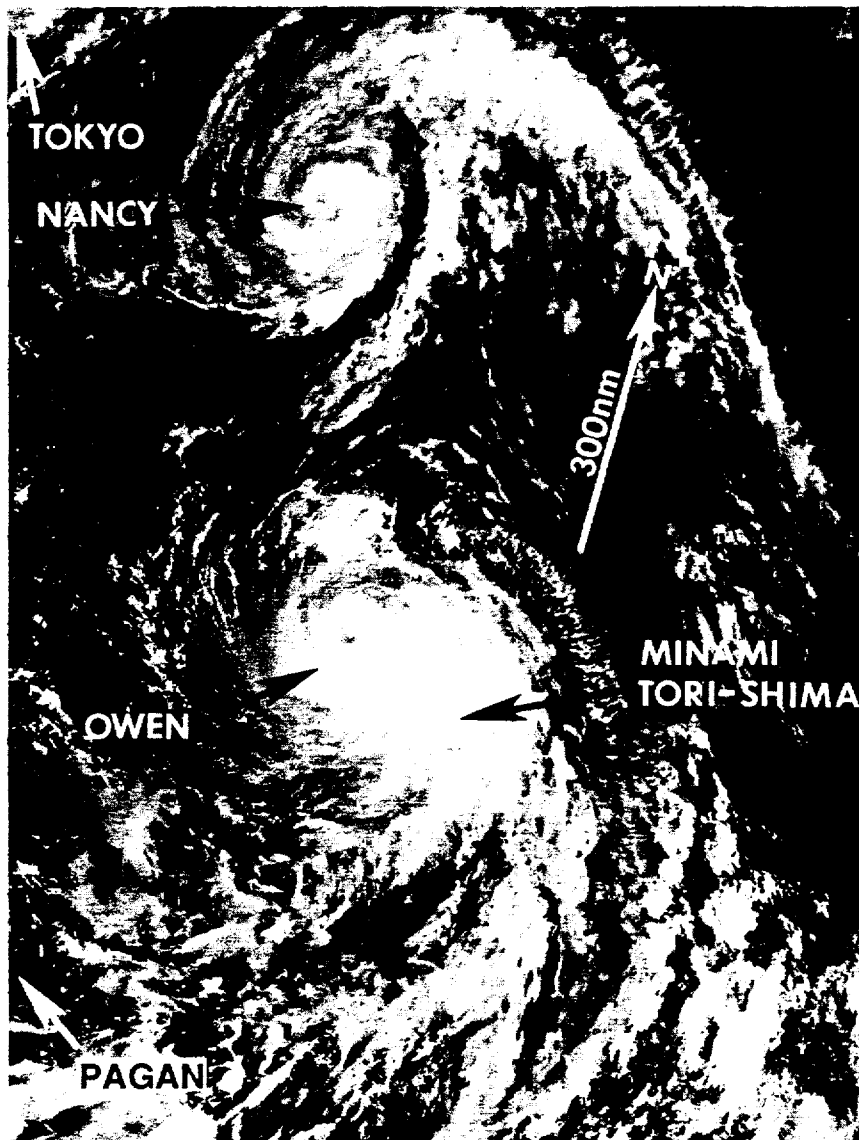


Figure 3-16-1. Typhoon Owen with a cloud filled eye follows Nancy (17W) north-northwestward (142243Z August DMSP visual imagery).

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E 125 130 135 140 145 150 155 160 165 170 E
N 50

TYPHOON NANCY
BEST TRACK TC-17W
09 AUG-18 AUG 89
MAX SFC WIND 75KT
MINIMUM SLP 967MB

45

40

35

30

25

20

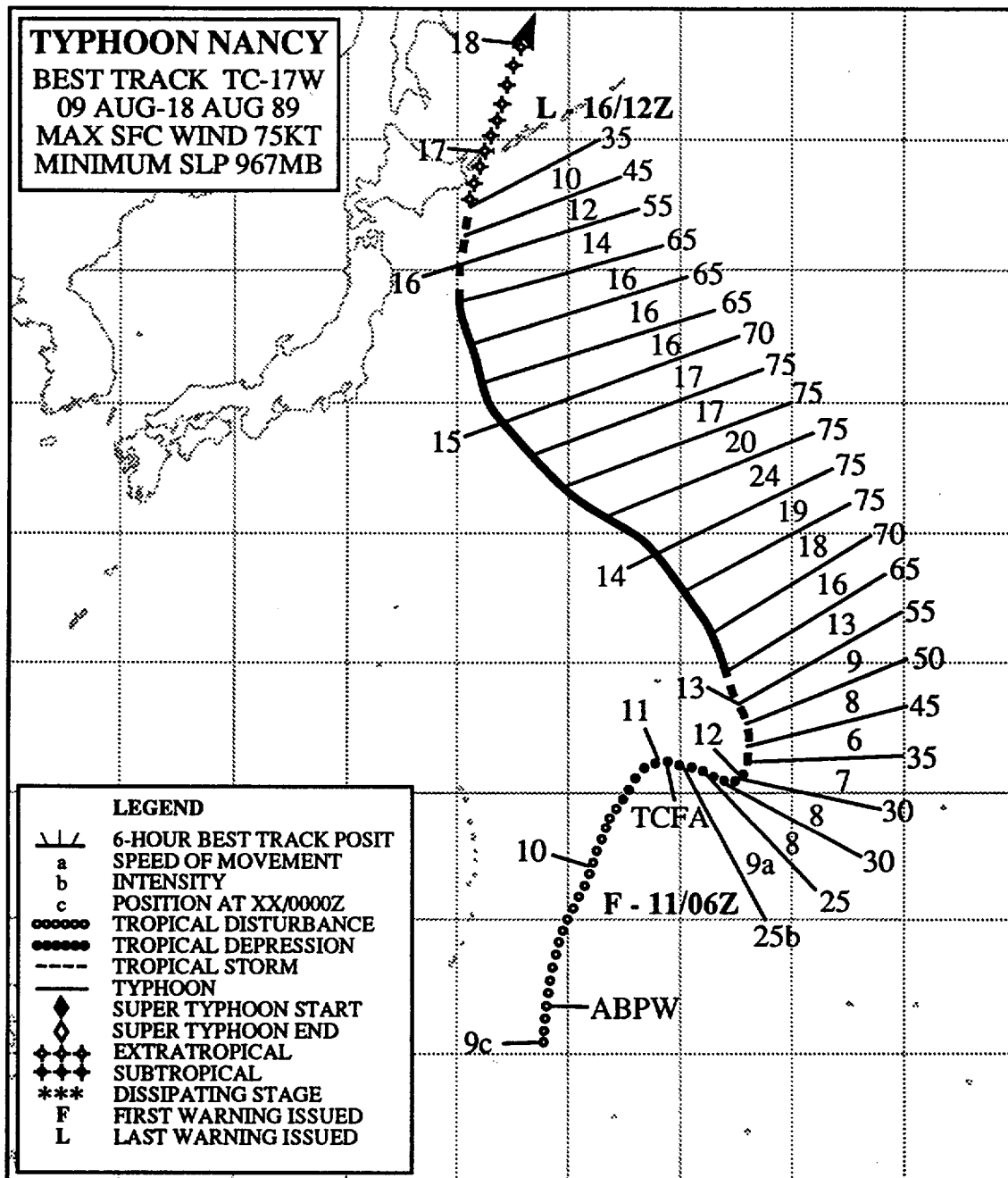
15

10

N 5

LEGEND

- 6-HOUR BEST TRACK POSIT
- a SPEED OF MOVEMENT
- b INTENSITY
- c POSITION AT XX/0000Z
- TROPICAL DISTURBANCE
- TROPICAL DEPRESSION
- TROPICAL STORM
- TYPHOON
- ◆ SUPER TYPHOON START
- ◆ SUPER TYPHOON END
- ◆ EXTRATROPICAL
- ◆ SUBTROPICAL
- *** DISSIPATING STAGE
- F FIRST WARNING ISSUED
- L LAST WARNING ISSUED



TYPHOON NANCY (17W)

Of the eight August tropical cyclones, Nancy was the third typhoon. It underwent a prolonged binary interaction with Typhoon Owen (16W), tracked rapidly toward Japan, then abruptly turned northward, and finally became extratropical.

The disturbance that eventually became Typhoon Nancy appeared as an area of persistent convection in the monsoon trough. It was first considered as a suspect area on the 9 August Significant Tropical Weather Advisory. The disturbance tracked northeastward in response to surging monsoon southwesterlies. At 110100Z, JTWC issued a Tropical Cyclone Formation Alert based on increased curvature in

the convective bands and a cyclonic tumbling motion of the convection on animated satellite imagery. The first warning for Tropical Depression 17W followed at 110600Z when satellite imagery revealed a developing central dense overcast. At first, JTWC forecast Tropical Depression 17W to make a curve to the north and then track northwestward, as it separated from the monsoon trough and interacted with the subtropical ridge which was building westward. The system did, indeed, follow the forecast, however, only after an unforecast 18-hour jog to the southeast. During this early stage, both Tropical Depressions 17W and 16W competed for low-level inflow and favorable upper-level outflow channels, causing

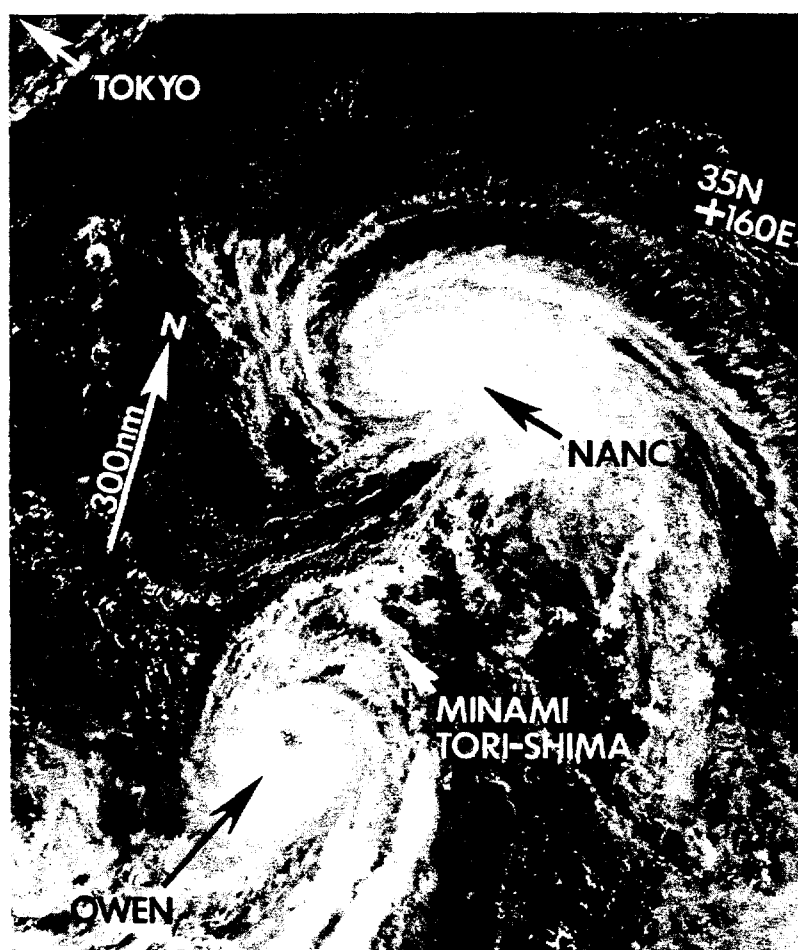


Figure 3-17-1. Typhoons Nancy and Owen (16W) at peak intensity (140313Z August NOAA infrared imagery).

a high degree of uncertainty as to which system would dominate.

As Tropical Depression 17W turned to the north, it was upgraded to Tropical Storm Nancy at 120600Z. Six hours later, Tropical Depression 16W also would become a tropical storm. Then, Nancy broke free of the monsoon trough and began rapid intensification, reaching typhoon intensity within 24 hours of its upgrade to a tropical storm.

JTWC anticipated the possibility of binary interaction with Tropical Depression 16W as soon as Nancy formed. While Tropical Depression 16W intensified, the two systems closed to within 600 nm (1110 km) of each other, and binary interaction became evident when Nancy turned northward. Nancy and Owen (16W) rotated around each other from 120000Z until 150000Z (Figure 3-17-1), an exceptionally long period. The rotation between the two systems about a common

center point totaled 105 degrees. During this time, Nancy accelerated from 6 kt (11 km/hr) on 12 August to 24 kt (44 km/hr) on 14 August in response to the combined effects of increased steering flow and the interaction with Owen (16W). A comparison of both typhoon tracks referenced to the center of motion, or centroid, is shown in Figure 3-17-2. The centroid's track (Figure 3-17-3) during the binary interaction moved east and then turned to the northwest. JTWC used this as a forecast aid for both cyclones, with good results. JTWC propagated the centroid northward, however, results would have been even better had JTWC steered the centroid with the north-northwestward steering flow. At 131800Z, Nancy reached a peak intensity of 75 kt (39 m/sec) and started accelerating towards Tokyo, a track that would reach the metropolis in 24 hours. Based on the expected behavior from the binary interaction, JTWC forecasters projected the cyclone to slow down and veer to the north. Twelve hours later, the forecast motion away from Japan

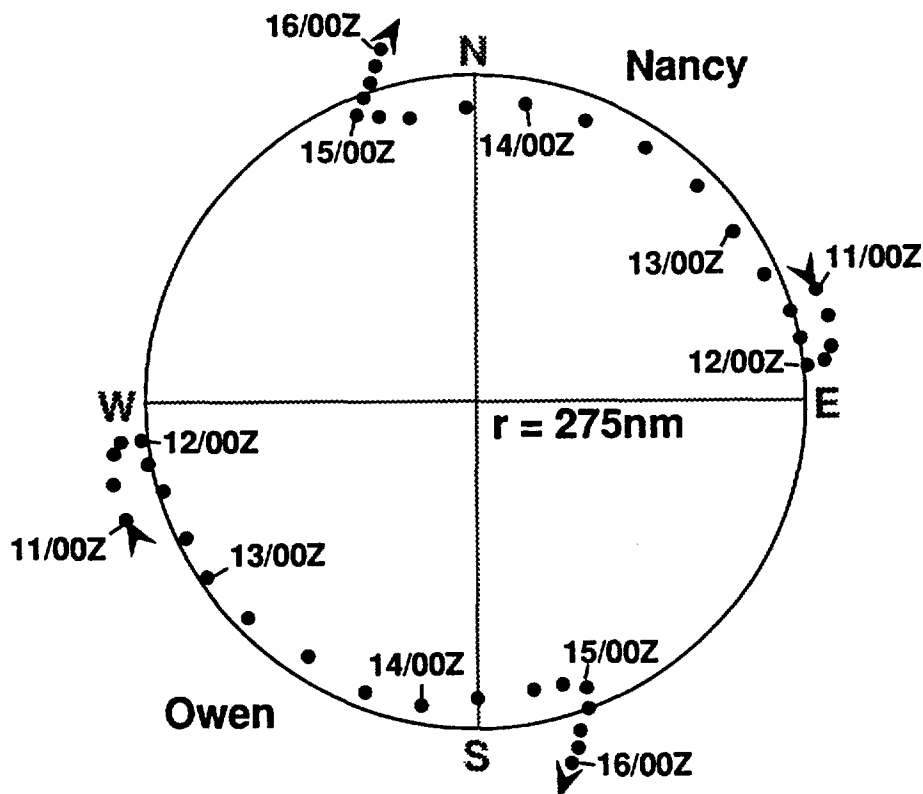


Figure 3-17-2. Tracks of Typhoons Nancy and Owen (16W) relative to their common center. Binary interaction lasted for 72 hours and through 105 degrees of rotation.

materialized. On 15 August, the binary interaction between Nancy and Owen (16W) ended abruptly. There is, to our knowledge, no research that indicates when a binary interaction will cease and the storms will resume independent tracks.

In retrospect, and in light of a similar north-orientated track of Typhoon Mac (15W) two weeks before, there was concern whether Nancy would cross over Japan. But, the NOGAPS prognostic series were quite consistent in moving a trough, which could

induce recurvature, to the east of Japan. The series also built a mid-tropospheric ridge that would stop any further northwest movement over the northern Sea of Japan. At 160000Z, Nancy was moving north of the mid-tropospheric subtropical ridge. It had weakened to tropical storm intensity, and began extratropical transition. Without deep convection to maintain the warm core, the cyclone completed its extratropical transition. The final warning was issued at 161200Z as the low-level circulation center tracked north-northeastward just east of Hokkaido.

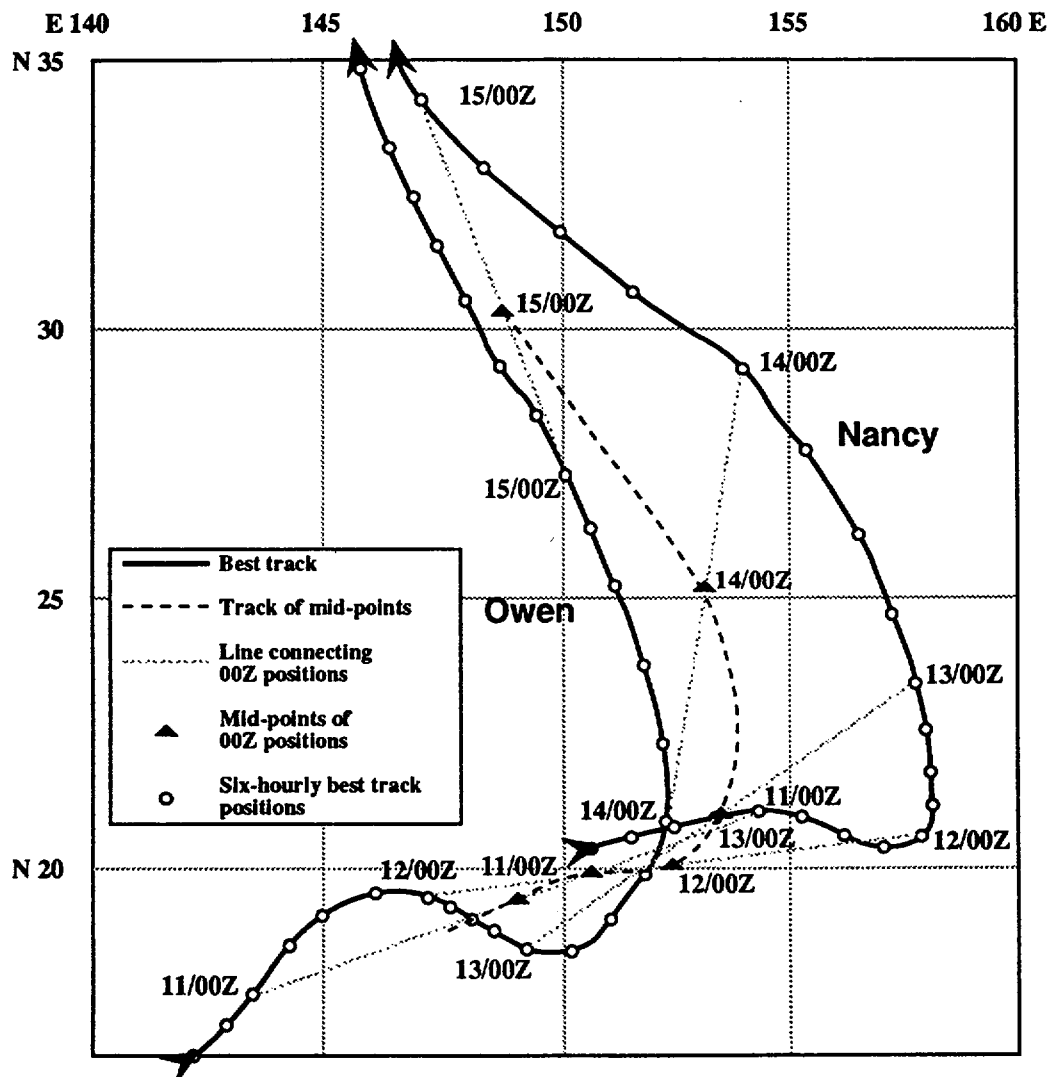


Figure 3-17-3. Path of mid-points between Typhoons Nancy and Owen (16W).

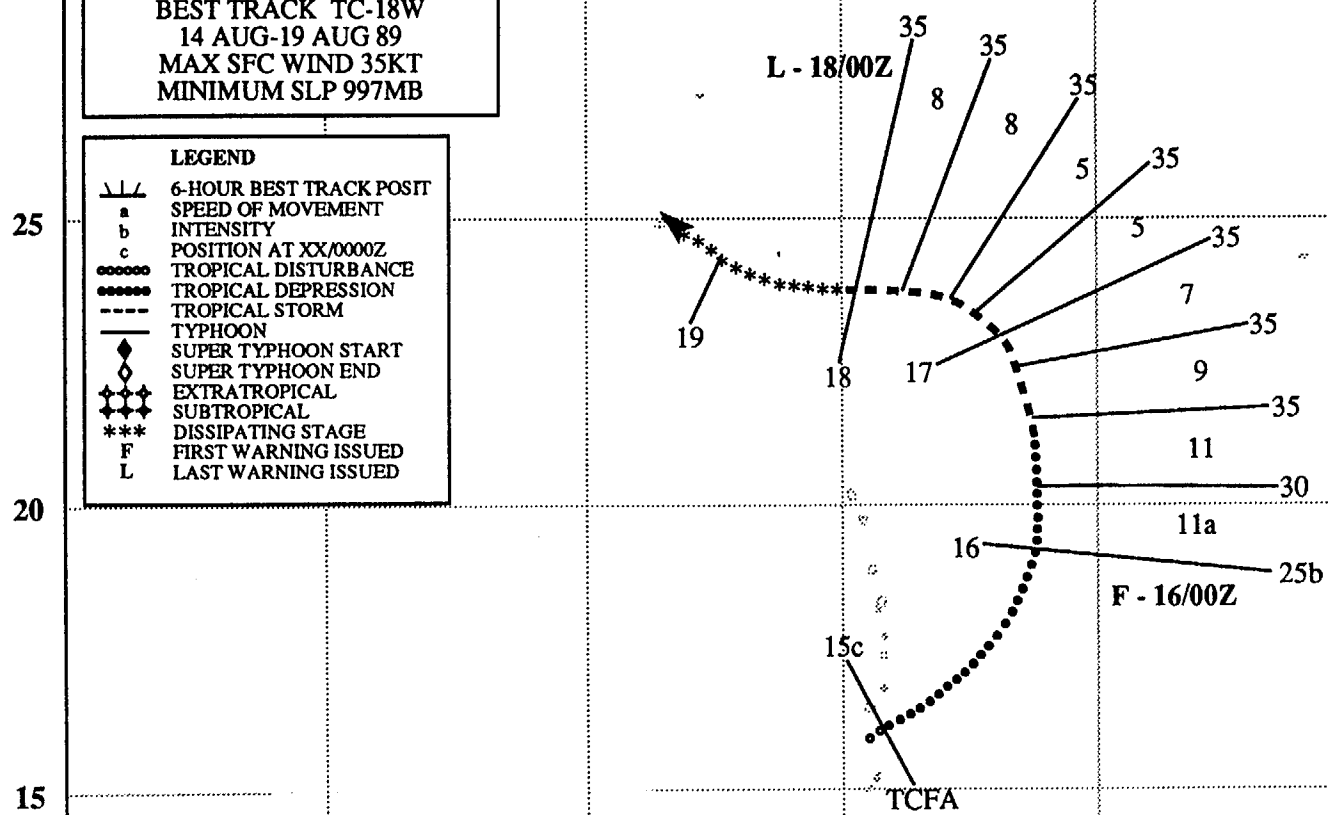
E 130 135 140 145 150 155 160 E

N 30

TROPICAL STORM PEGGY
 BEST TRACK TC-18W
 14 AUG-19 AUG 89
 MAX SFC WIND 35KT
 MINIMUM SLP 997MB

LEGEND

\ / \ / 6-HOUR BEST TRACK POSIT
 a SPEED OF MOVEMENT
 b INTENSITY
 c POSITION AT XX/0000Z
 ○○○○○○ TROPICAL DISTURBANCE
 ●●●●●● TROPICAL DEPRESSION
 - - - - TROPICAL STORM
 - - - - TYPHOON
 ◆ SUPER TYPHOON START
 ◇ SUPER TYPHOON END
 + + + + EXTRATROPICAL
 + + + + SUBTROPICAL
 *** DISSIPATING STAGE
 F FIRST WARNING ISSUED
 L LAST WARNING ISSUED



106

N 10

TROPICAL STORM PEGGY (18W)

The third tropical cyclone to develop in the monsoon trough between 11 and 16 August, Peggy was short-lived and only reached minimal tropical storm intensity.

While tropical cyclones Owen (16W) and Nancy (17W) were completing their binary interaction and moving northward, the disturbance that would eventually become Peggy formed in the monsoon trough roughly 200 nm (370 km) north of Guam. Late on 14 August, satellite imagery displayed a new area of convection associated with a low-level circulation center. After sparse synoptic data indicated falling pressures and wind shifts

reflected the circulation's development, JTWC issued a Tropical Cyclone Formation Alert at 150000Z.

Initially, the disturbance moved northeastward and a small ragged area of central convection persisted. This persistent, but small, central dense overcast led JTWC to issue the first warning on Tropical Depression 18W at 160000Z. The depression then turned north to follow Owen's (16W) track. Increased convection resulted in an upgrade to tropical storm intensity on the 161200Z warning. The outflow from Owen (16W) restricted Peggy's outflow aloft. This increased vertical shear, in combination with the subsidence associated with a Tropical Upper Tropospheric Trough (TUTT) cell to the northeast, kept Peggy from developing further. Minor flare-ups of convection were, however, sufficient to allow Peggy to maintain its 35-kt (18 m/sec) intensity despite the shear. Meanwhile, lower tropospheric ridging northeast of Peggy caused the cyclone to turn to the west. At 180000Z, the final warning was issued when satellite imagery (Figure 3-18-1) indicated the separation of the low-level circulation from its convection and that the low-level center would remain in an area of strong subsidence. The residual low-level vorticity center drifted west-northwestward and dissipated on 19 August near Iwo Jima.

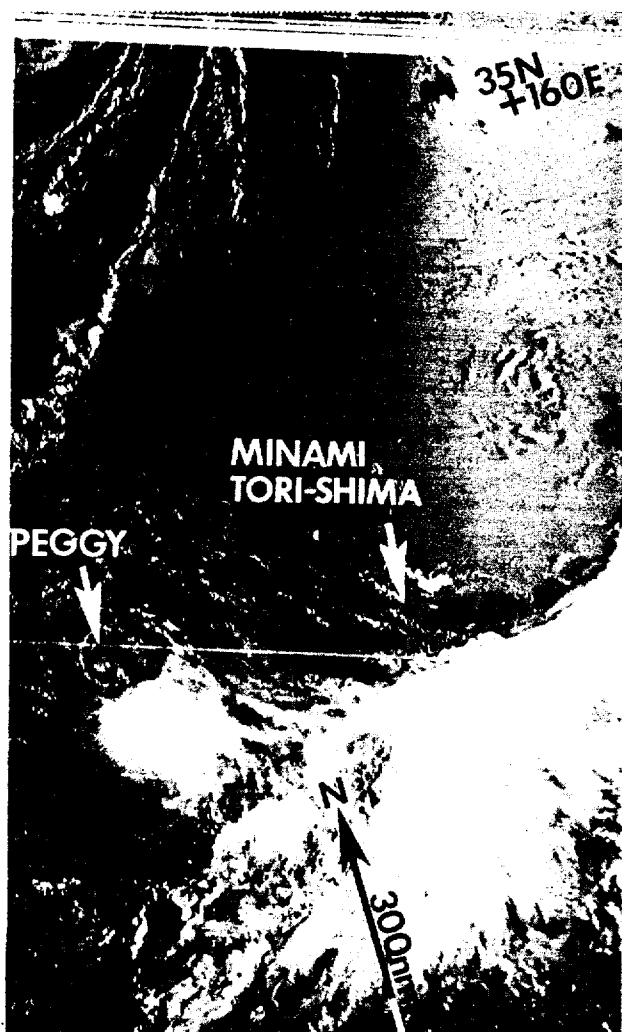
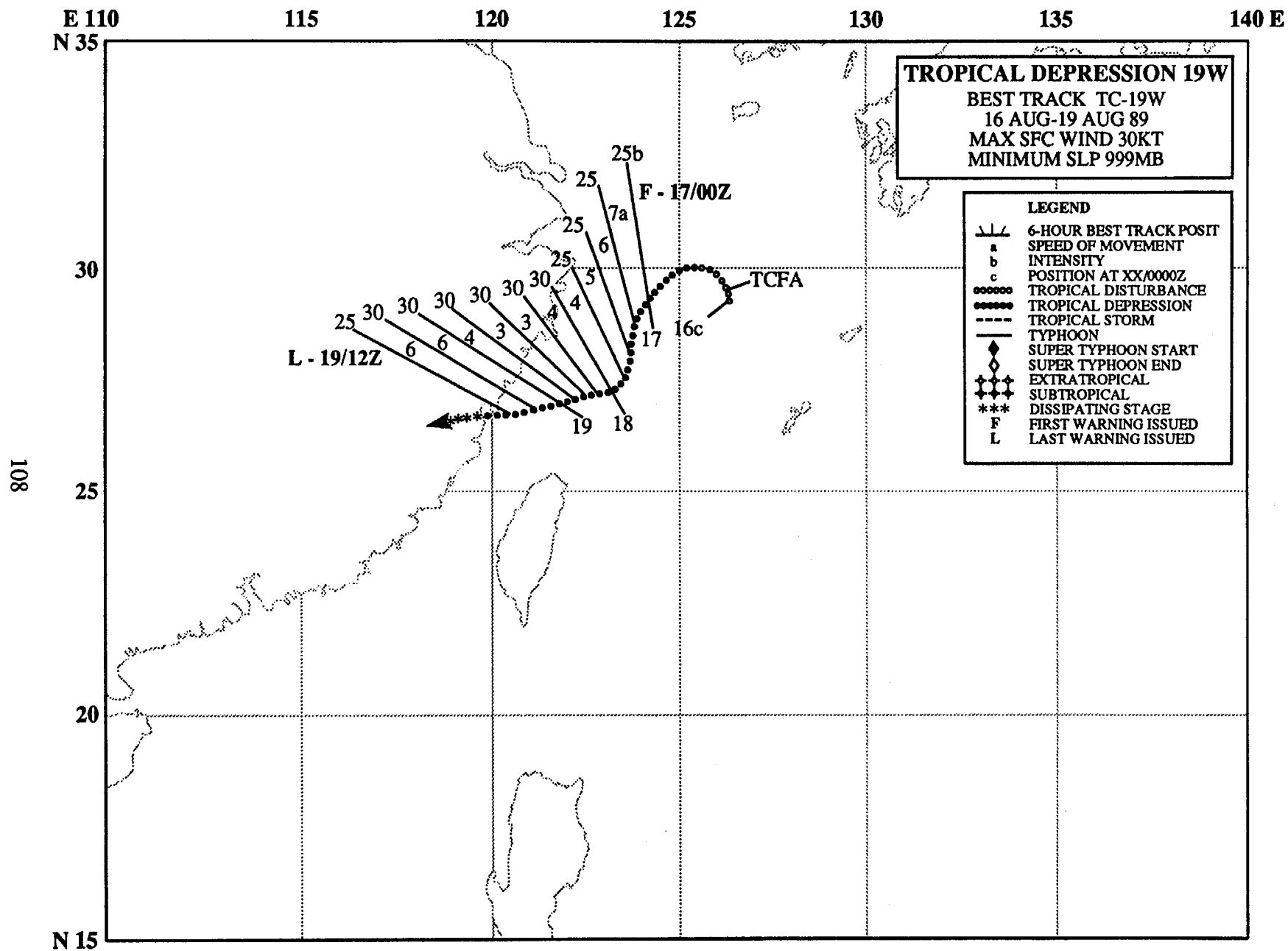


Figure 3-18-1. Vertical wind shear from the northwest exposes the low-level circulation center as a TUTT cell to the northeast of Peggy is becomes the dominant feature (172206Z August NOAA visual imagery).



TROPICAL DEPRESSION 19W

Developing from a large area of low pressure and disturbed weather, this system was first detected on satellite imagery approximately 180 nm (335 km) northwest of Okinawa on 16 August. Initially, there was just a large cloud minimum area that was caused by subsidence beneath a mid-level low. Based on the expected movement of upper-level divergence into this area, JTWC forecast the development of Tropical Depression 19W. When strong upper-level divergence did move into this area, convection began to rapidly develop. This cloudiness began to coil beneath the mid-level low, and estimates of 20- to 25-kt (10- to 13-m/sec) surface winds from satellite data prompted the issuance of a Tropical Cyclone

Formation Alert at 160230Z. The first warning, at 170000Z, addressed further development of the tropical cyclone.

Tropical Depression 19W's unusual curved track to the north, west, and then south appears to coincide with the overall motion displayed by the larger, mid-level low. On 18 August, the mid-level low began to fill, weakening its influence on the tropical depression (Figure 3-19-1). The track of the cyclone straightened out, moving westward with the easterly steering flow. JTWC issued the final warning at 191200Z as the tropical depression approached the coast of China. No reports of damage were received.

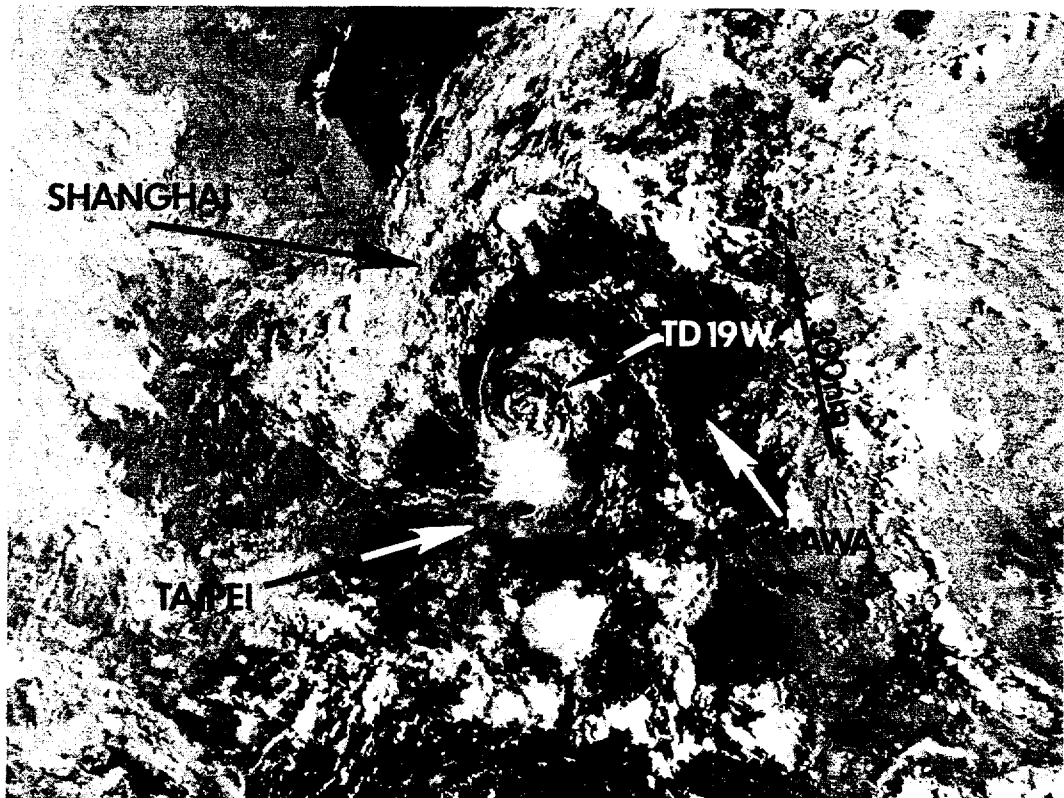
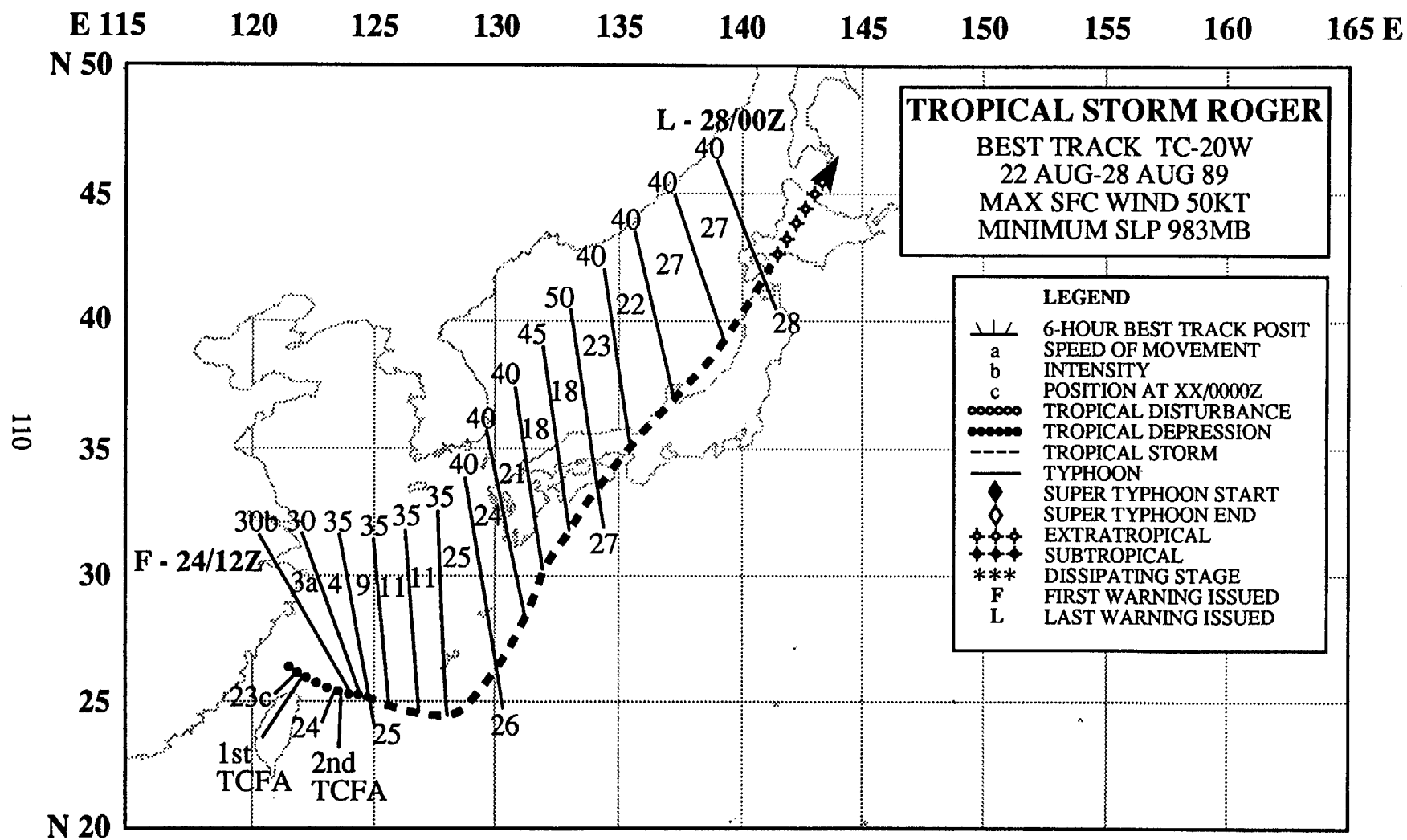


Figure 3-19-1. A tight spiral of low cloudiness is associated with the exposed low-level circulation of Tropical Depression 19W (172346Z August NOAA visual imagery).



TROPICAL STORM ROGER (20W)

Forming just north of Taiwan, Roger moved southeastward into the southern Ryukyu Islands, abruptly turned northeastward, and made landfall on Honshu. At the start, the forecast problem for this tropical cyclone was exacerbated by the difficulty in locating the system's complex center during its formative stages and the immediate threat it posed to DOD assets on Okinawa.

On 23 August, a tropical disturbance rapidly consolidated just north of Taiwan. Because of the developed cloud signature, JTWC opted to issue a Tropical Cyclone Formation Alert at 230500Z instead of reissuing the Significant Tropical Weather Advisory. When further development did not occur as rapidly as anticipated, the Alert was reissued the following day. Satellite data detected multiple vortices near the main convection mass and there was uncertainty about just where the system was going to consolidate. The fairly dense network of ship and land observations in the southern Ryukyu Islands began to show significant 12-hour pressure falls, and winds near the center of the disturbance increased to 25 kt (13 m/sec). In response, JTWC issued a 36-hour Tropical Depression Warning at

241200Z. Pressures continued to drop during the following 12 hours, and satellite and synoptic fixes appeared to converge. Finally, when it became apparent that one circulation center was going to emerge and intensify, JTWC issued a 72-hour Tropical Cyclone Warning at 250000Z.

On 25 August, in response to a short wave trough approaching from the north-northwest, the depression turned northeastward. The reason for the abrupt track change to the northeast was not immediately apparent because two vortices were involved. The low-level circulation center, in the southern portion of the cloud system, weakened, and another center in the northern portion strengthened. This switch in circulation centers initially made it appear as if Roger had executed a sharper turn and had accelerated faster than it actually did.

In addition to the major track change on 25 August, Roger also intensified to a tropical storm. Synoptic data revealed that gale force winds extended out from the circulation center more than 300 nm (555 km) into the southeastern semicircle. This large asymmetrical pattern of gales would accompany

Roger during the remainder of its lifetime. As the tropical cyclone (Figure 3-20-1) moved steadily northeastward, it gradually intensified. Roger reached a peak intensity of 50 kt (26 m/sec) early on 27 August, just prior to making landfall on Shikoku at Cape Muroto, which is located 100 nm (185 km) southwest of the city of Osaka.

At landfall, Roger's convection became more centralized and upper-level outflow remained good. In addition, the cyclone accelerated, increasing winds in the southeastern semicircle. As a consequence, Roger's track across central Honshu created considerable havoc. Two people drowned in swollen rivers and a third was killed in one of many landslides. Some areas in Roger's path recorded over 19 inches (485 mm) of rain.

Widespread disruption of air traffic and railway service stranded over 37,000 travelers. Also, due to high winds, the new Seto Ohashi Bridge across the Inland Sea between Honshu and Shikoku was closed for the first time since it opened in April 1988.

At 271200Z, Tropical Storm Roger moved into the Sea of Japan and continued to accelerate under the influence of stronger westerly winds aloft. Even though the circulation center was over water, the combined effects of surface friction from the rugged topography of northern Honshu and increased westerly winds aloft weakened the tropical cyclone. At 280000Z, the final warning was issued as the extratropical remnants of Roger sped northeastward across Hokkaido.

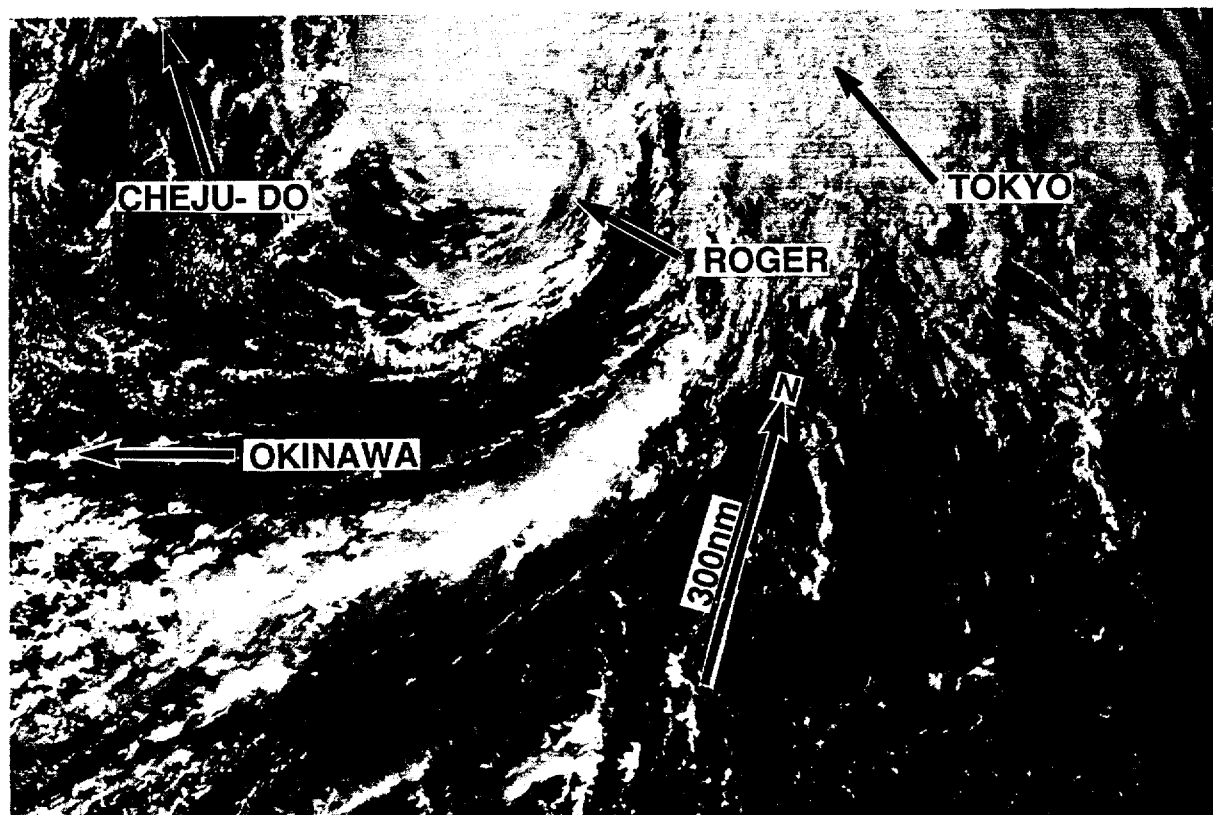


Figure 3-20-1. Near peak intensity, Roger approaches central Honshu (262343Z August DMSP visual imagery).

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E 130 135 140 145 150 155 160 165 170 E

N 40

TROPICAL DEPRESSION 21W
 BEST TRACK TC-21W
 23 AUG-29 AUG 89
 MAX SFC WIND 30KT
 MINIMUM SLP 1000MB

LEGEND

- 6-HOUR BEST TRACK POSIT
- a SPEED OF MOVEMENT
- b INTENSITY
- c POSITION AT XX/0000Z
- TROPICAL DISTURBANCE
- TROPICAL DEPRESSION
- TROPICAL STORM
- TYPHOON
- ◆ SUPER TYPHOON START
- ◇ SUPER TYPHOON END
- ◆◆◆ EXTRATROPICAL
- ◆◆◆ SUBTROPICAL
- *** DISSIPATING STAGE
- F FIRST WARNING ISSUED
- L LAST WARNING ISSUED

35

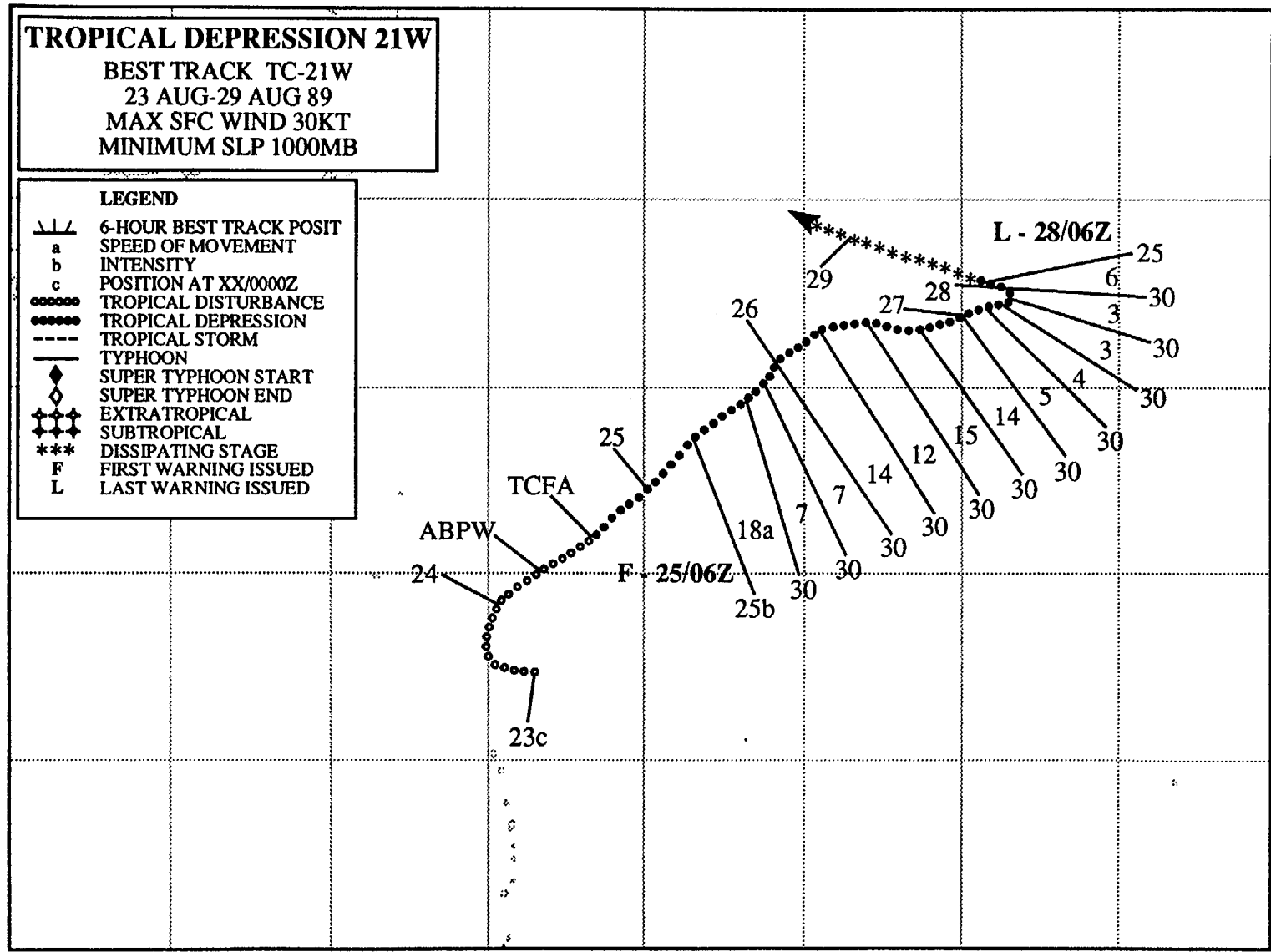
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N 15

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TROPICAL DEPRESSION 21W

The eighth and final tropical cyclone of August, Tropical Depression 21W developed northeast of the Mariana Islands. Because JTWC recognized that intensification would be inhibited by strong vertical wind shear, only Tropical Depression Warnings were issued.

As Tropical Storm Roger (20W) passed through the southern Ryukyu Islands on 23 August, a disturbance formed on the eastern end of the monsoon trough which extended

eastward across the northern-most Mariana Islands. The 24 August Significant Tropical Weather Advisory mentioned the disturbance and its poor potential for development. During the night, the disturbance became better organized and its potential for development was upgraded to fair. A Tropical Cyclone Formation Alert was issued at 241200Z, after the disturbance continued to develop during the normal diurnal convective minimum. Further development (Figure 3-21-1) led to the first



Figure 3-21-1. Convective organization continues to increase after the Alert was issued (242242Z August DMSP visual imagery).

warning at 250600Z. A Tropical Depression Warning was issued rather than a tropical cyclone warning since the low-level circulation was displaced to the west of the deep convection and the system was not expected to be long-lived because of strong westerly wind shear aloft.

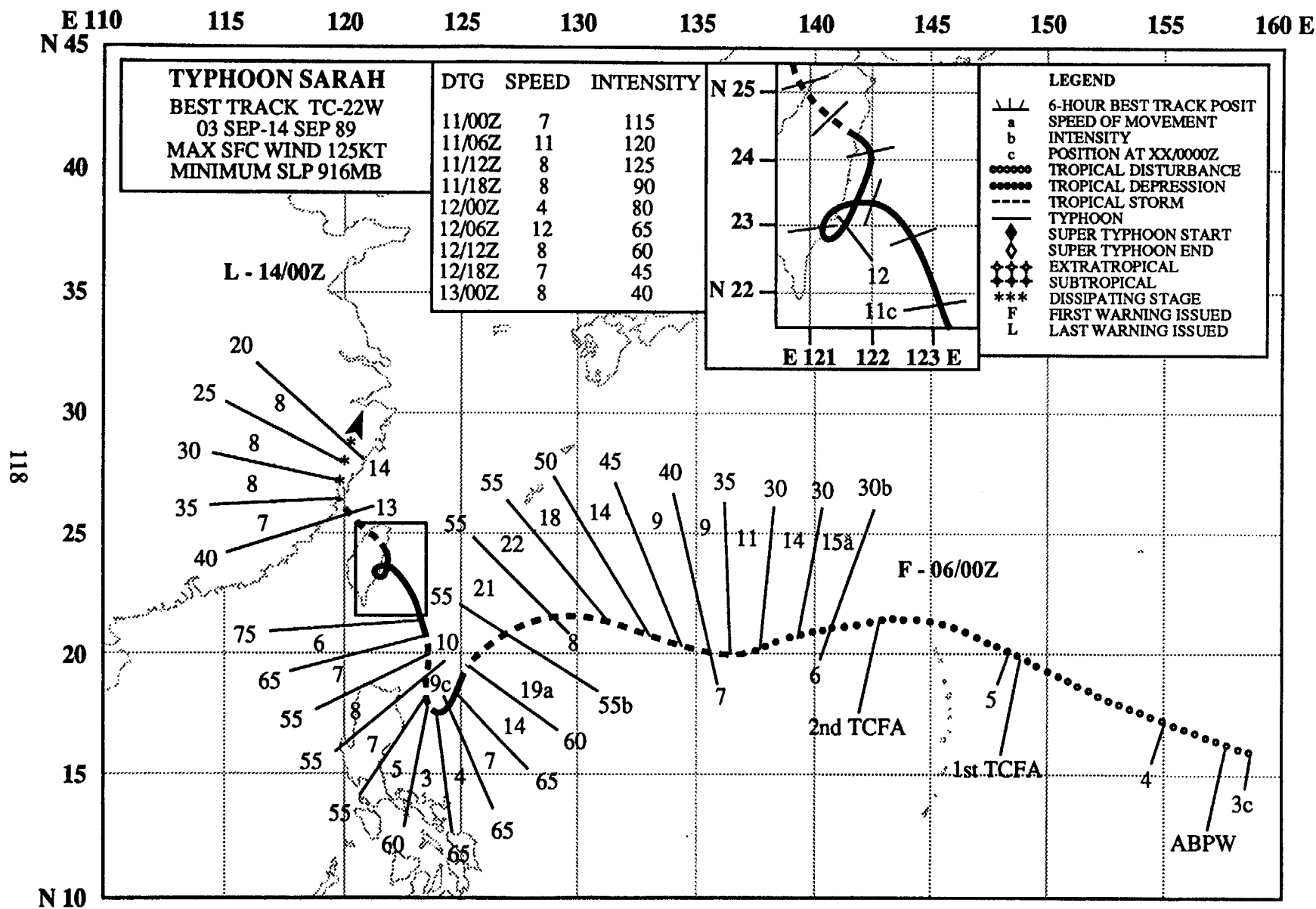
While the upper-level winds restricted the tropical cyclone's outflow, the deep southwesterly monsoonal flow carried the low-level circulation center on an unusually long track to the northeast. Late on 25 August, Tropical Depression 21W slowed abruptly as it moved into an area of weaker vertical shear. Coincidentally, the low-level circulation center moved beneath the central cloud mass, and the intensity increased to 30 kt (15 m/sec).

On 26 August, the depression accelerated in response to a surge in the southwest

monsoon. Shortly thereafter it started interacting with a shear zone that trailed from a weak cold front. Tropical Depression 21W appeared to be on the verge of transitioning to an extratropical system; however, on 27 August, mid-level steering weakened, the system stalled, and central convection reappeared.

Within a day, unfavorable conditions returned aloft, as northwesterlies moved over the system and began once more to strip away the central convection. As a consequence, the amount of convection decreased and the low-level circulation center became exposed. A weakening Tropical Depression 21W suddenly started tracking northwestward. At 280600Z, with the low-level circulation center separated more than one degree to the west of the convection, the final warning was issued. JTWC did not receive any reports of damage caused by the tropical cyclone.

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TYPHOON SARAH (22W)

The first of the September tropical cyclones, Sarah proved to be a bona fide challenge to forecasters. The cyclone apparently underwent a binary interaction with a secondary low east of Luzon and later, when it stalled, was involved with the development of a sympathetic low* on the lee side of Luzon. From genesis involving two distinct cloud masses to accelerating toward the Philippines, stalling just east of Luzon, moving north and rapidly reintensifying, then looping over eastern Taiwan, Sarah was one of the most difficult storms of the year to forecast.

The first day of September, the monsoon trough stretched across the western Pacific in a southwest to northeast orientation between 10° to 20° north latitude, and supported several discrete convective cloud masses. Near Minami Tori-shima, a distinct TUTT cell was evident in satellite imagery. About 600 nm (1110 km) to the southeast, a disturbed area of weather persisted in the monsoon trough. There was little convection associated with the TUTT cell, however, the convection associated with the

disturbance was listed on the Significant Tropical Weather Advisory. Two Tropical Cyclone Formation Alerts were issued before the first warning. Complex interactions between the TUTT cell, the disturbance and a second disturbance resulted in conditions favorable for development, and the first warning on Tropical Depression 22W was issued at 060000Z.

The Depression tracked as forecast to the west and was upgraded to Tropical Storm Sarah on the 061800Z warning. By midday on 7 September, Sarah started to accelerate to the northwest towards Okinawa and the tropical storm was relocated on the 071800Z to reflect the acceleration.

Forecasters at JTWC expected the north-westward motion to be short-lived and predicted a turn back to the west. However, on 8 September, the tropical storm turned west-southwest, then south-southwest, and nearly stalled east of Luzon on 9 September. Binary interaction with a secondary low appeared to be

* The formation of a sympathetic low is documented in relation to systems approaching Taiwan (Brand and Blueloch, 1973), but not for systems off the Philippine Islands

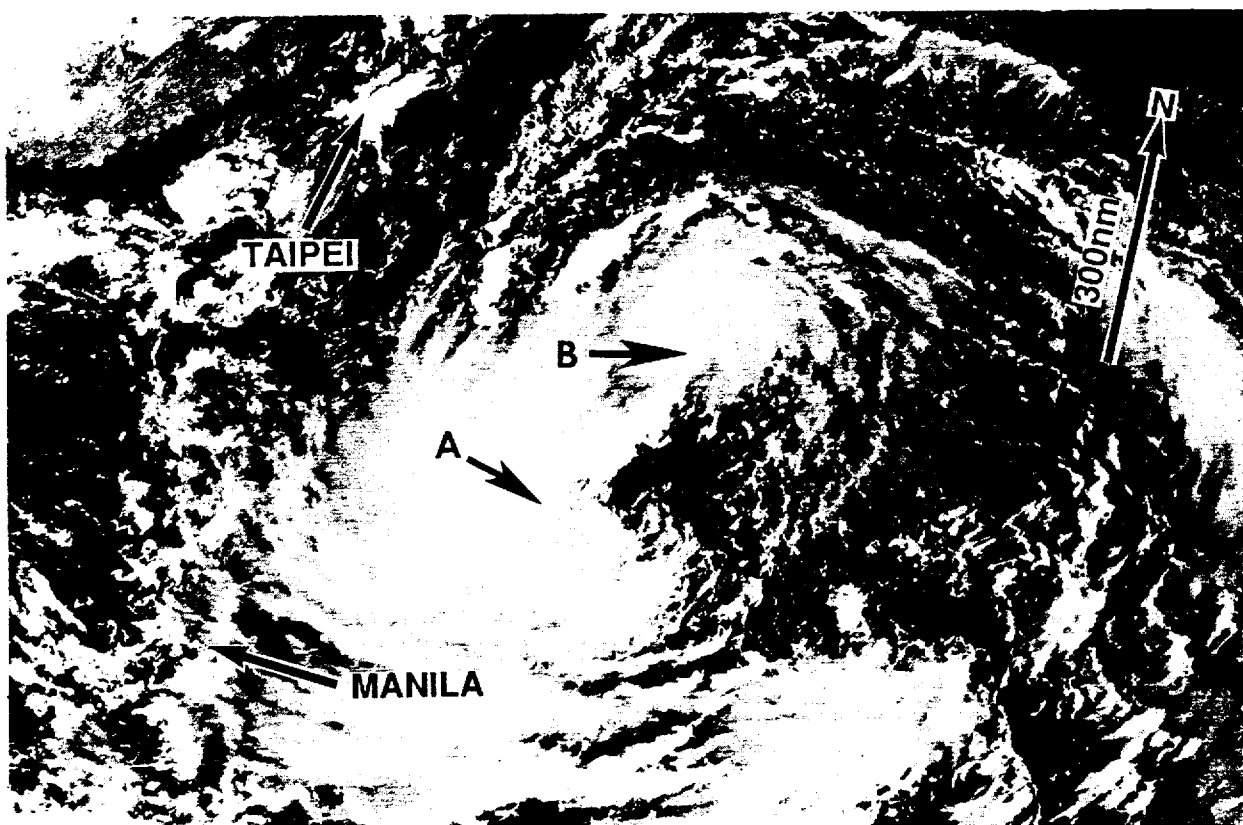
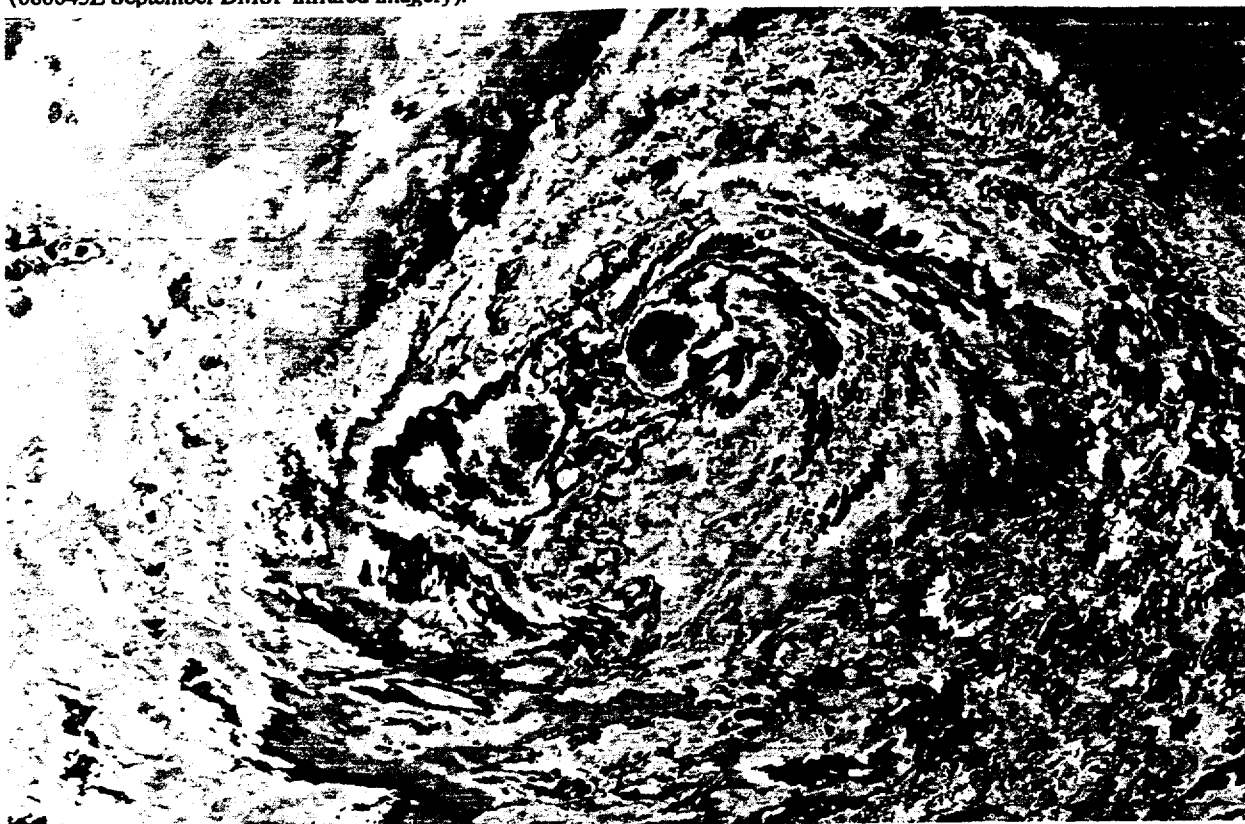


Figure 3-22-1. Matched pair of visual (above) and enhanced infrared (below) images showing two centers of convection. Point A is the mass of persistent convection that appears to have undergone binary interaction with Sarah which is at point B (080043Z September DMSP infrared imagery).



the cause for Sarah's unusual movement. While there was a persistent convective mass (Figure 3-22-1) on the satellite images, there was no firm evidence of this secondary low at the surface on 8 September.

Upgraded to typhoon intensity at 081800Z, Sarah drifted south slowly and then abruptly headed north. During this time, a sympathetic lee-side low (Figure 3-22-2) formed along the northwest side of Luzon. As Sarah moved north, the cloud mass associated with this lee-side low crossed Basco Island north of Luzon and tracked rapidly around the east side of Sarah and to the northeast. Since Basco Island (WMO 98135) reports did not indicate a wind shift as the convective mass

passed by, no Alert on this secondary convective area was issued. Sarah's prolonged stay just east of Luzon, coupled with the enhanced southwesterly monsoon flow being drawn over the Philippine Islands resulted in at least 31 fatalities, and extensive property and crop damage on Luzon. In addition, rare tornadoes touched down on 10 September. One caused approximately \$150,000 of damage to the San Miguel Naval Communications Station located 38 nm (70 km) northwest of Manila. No other U. S. military installations reported major damage. Camp John Hay located near Baguio reported the strongest winds observed at a U.S. military installation of 42 - 48 kt (22-25 m/sec) during the period from 091500Z to 110430Z.

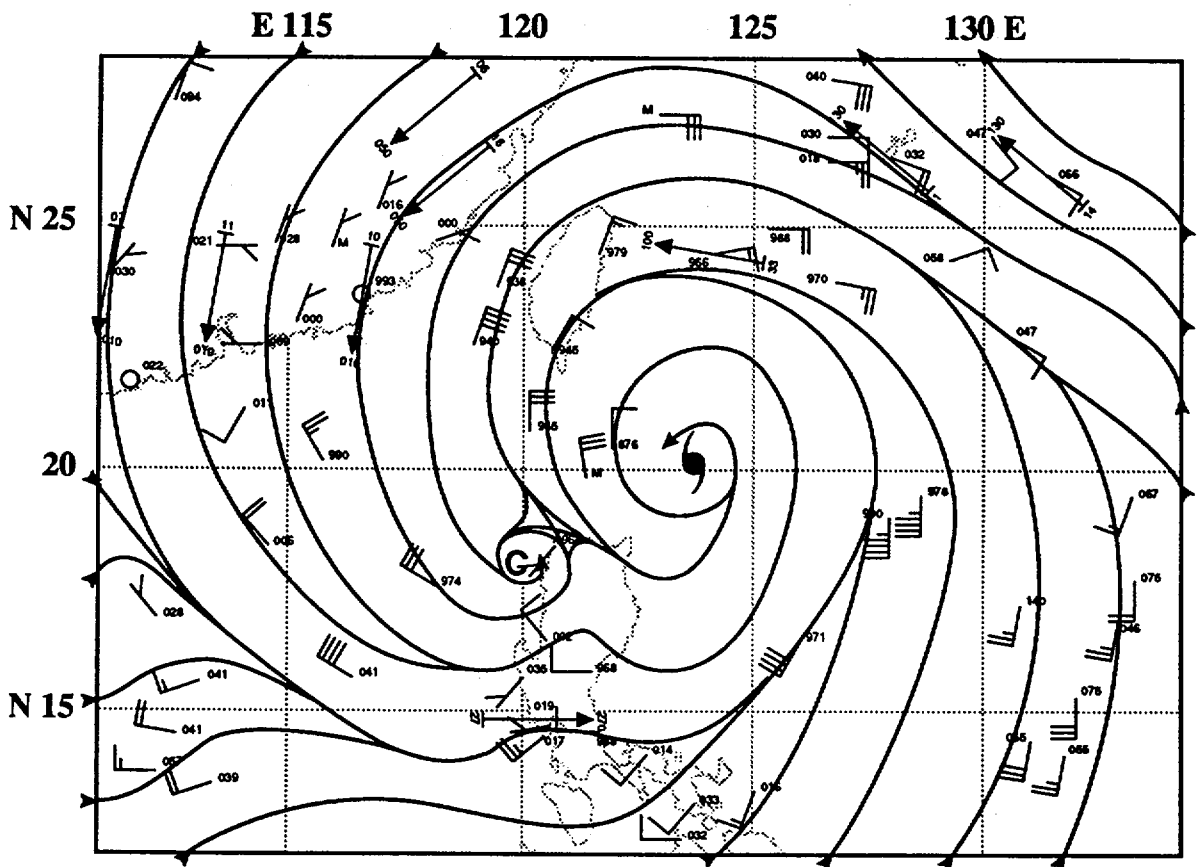


Figure 3-22-2. 101220Z surface/gradient wind analyses shows the sympathetic low along the northwest coast of Luzon.

Moving north into an area of efficient multiple outflow channels, Sarah (Figures 3-22-3 and 3-22-4) explosively deepened. The typhoon peaked at 125 kt (64 m/sec) before interaction with the rugged mountains of Taiwan caused it to weaken. On 10 September, the typhoon was forecast to track north, passing approximately 60 nm (110 km) east of Taiwan on 11 September. It was expected to merge with an approaching mid-latitude front and recurve to the northeast into Kyushu, Japan. Although this was the overall track taken by the secondary cloud maximum that had formed on

the lee-side of Luzon and looped around the east side of Sarah as both systems moved north, Sarah did not follow suit. Sarah moved on-shore Taiwan with maximum winds near 90 kt (46 m/sec). It then tracked south a short distance along the eastern edge of the mountain range and finally completed a counterclockwise loop off the coast. Approximately 12 hours later, Sarah reentered the coast farther north, weakened and was downgraded to a tropical storm Sarah at 121200Z as it crossed the rugged mountains of Taiwan. The cyclone did not regain its organization as it crossed the Taiwan

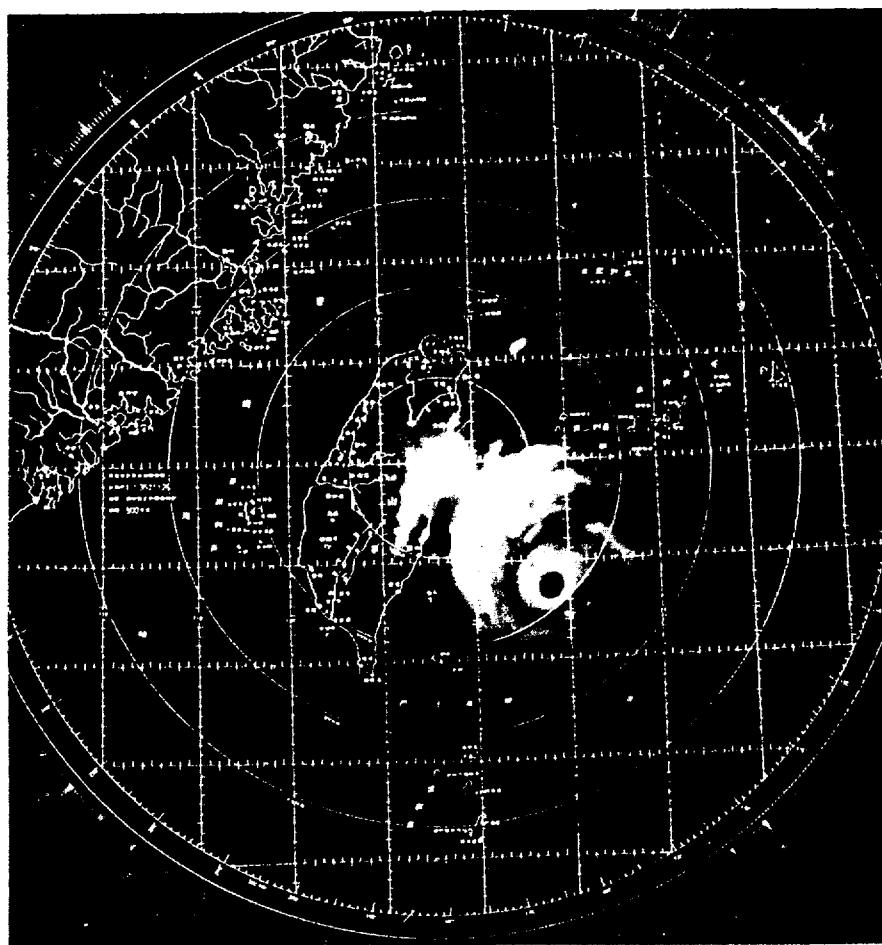


Figure 3-22-3. Radar display of Sarah from Hualien (WMO 46699) at 110500Z. Comparison with Figure 3-22-4, which is close in time, shows the contrast between the remotely sensed precipitation echoes from radar and the cloud top topography as viewed from space (photograph courtesy of the Central Weather Bureau, Taipei, Taiwan).

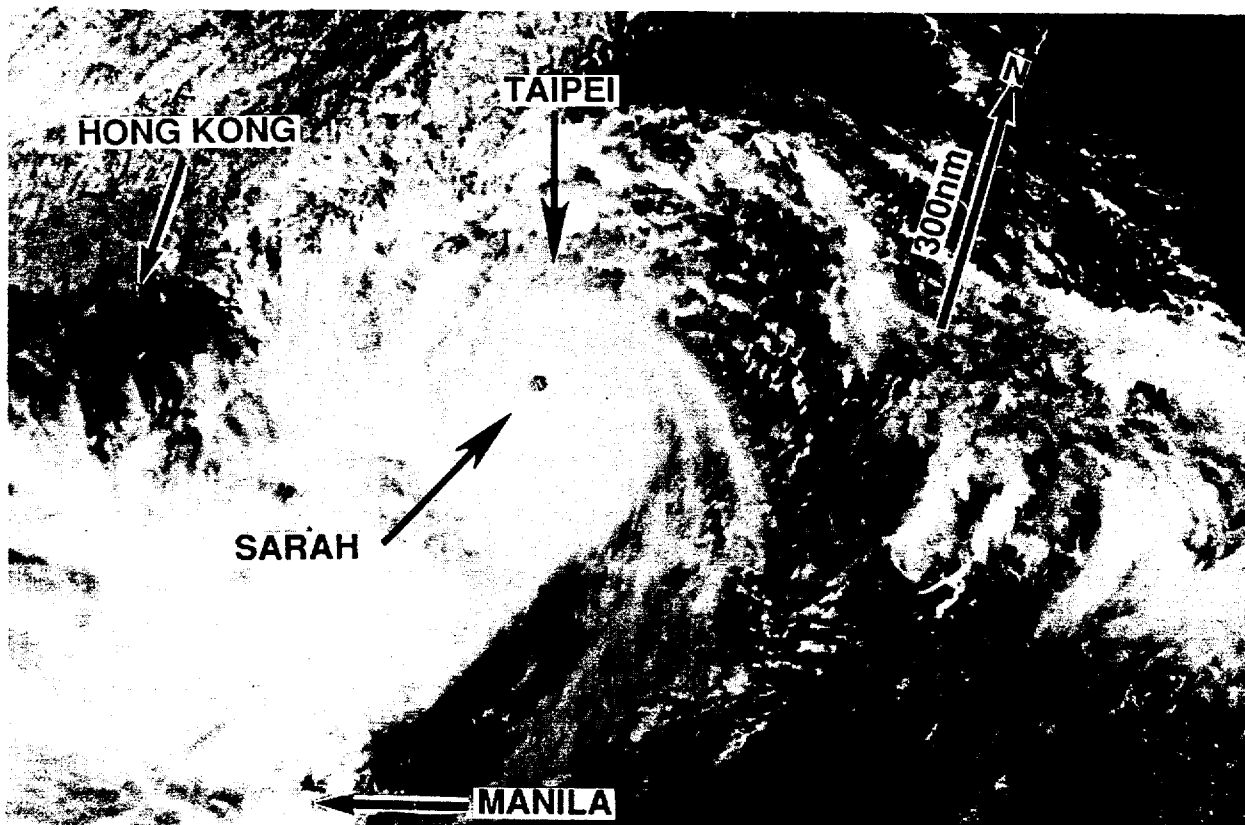
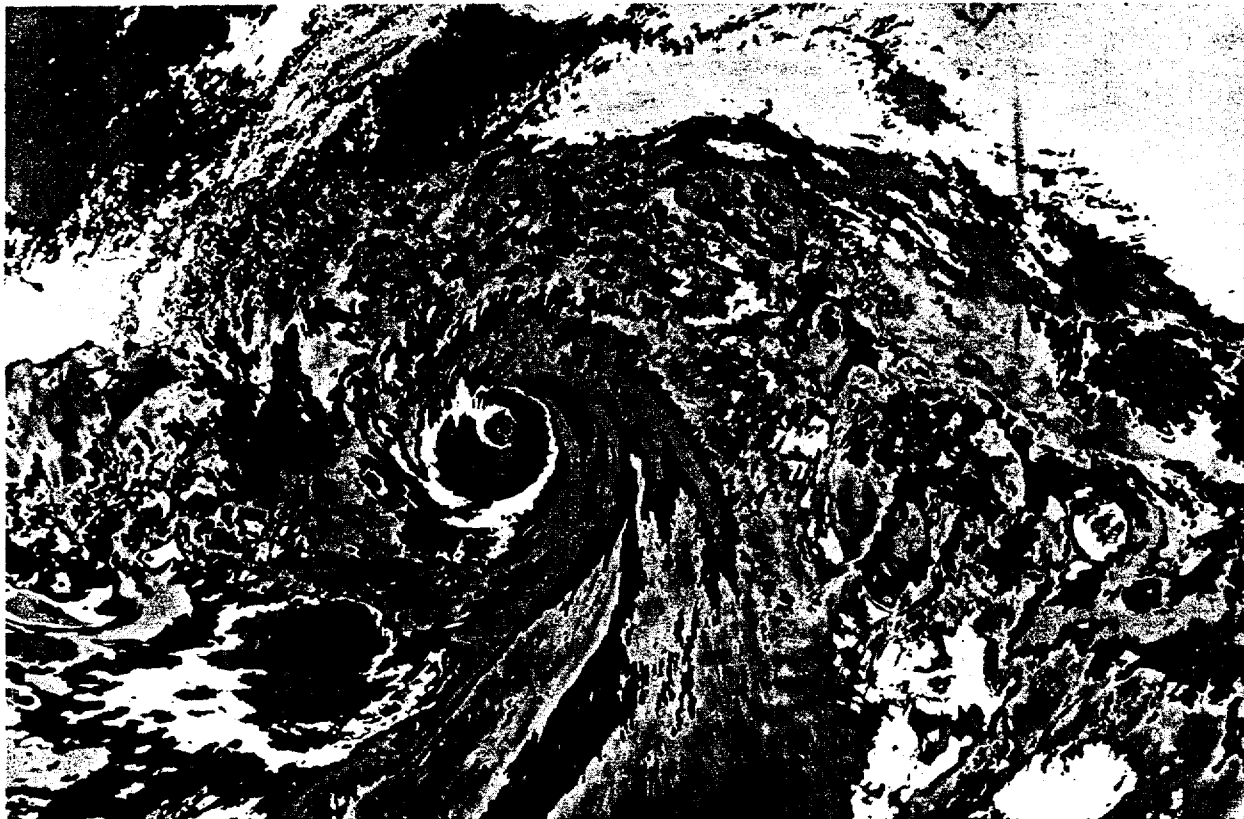


Figure 3-22-4. Matched visual (above) and enhanced infrared (below) pair of images showing Sarah near peak intensity (100517Z September DMSP visual and infrared imagery).



Straits and was downgraded to a tropical depression after it entered the eastern coast of China at 130600Z (Figure 3-22-5). The last warning was issued at 140000Z as the system dissipated over eastern China. Press reports

indicated that 13 people died on Taiwan, and that the 12000-ton freighter **Lung Hao** (Figure 3-22-6) broke in half off Hualien, Taiwan. No reports of damage were received from China.

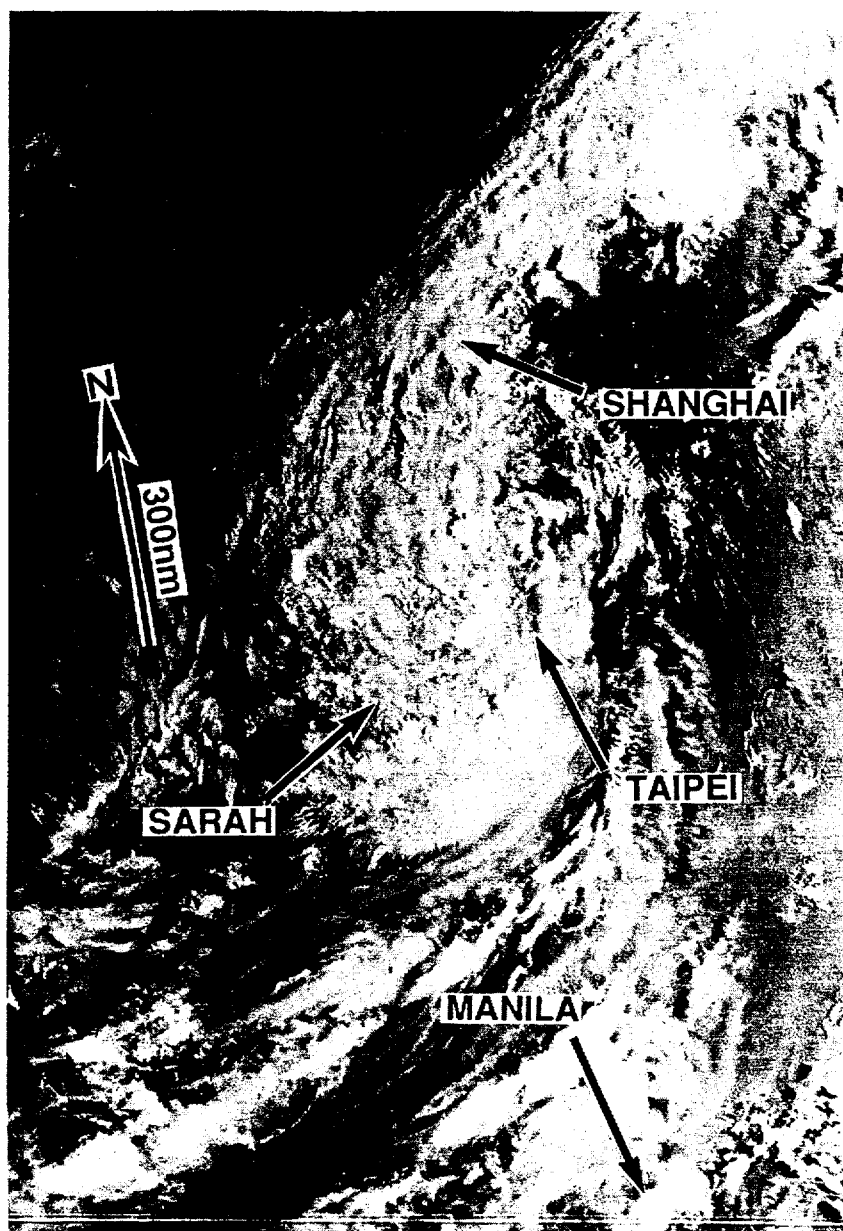


Figure 3-22-5. Sarah weakens over the coast of China (130006Z NOAA visual imagery).

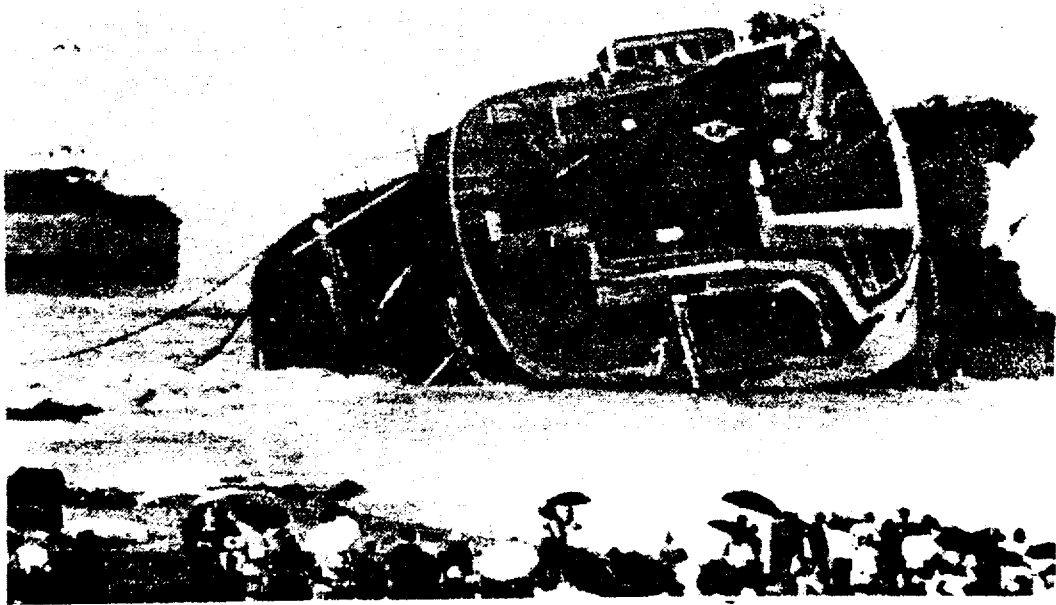


Figure 3-22-6. The wreck of the freighter Lung Hao, which was broken in half on the coast of Taiwan by Typhoon Sarah (photo courtesy *Pacific Daily News*, Agana, Guam).

E 120 125 130 135 140 145 150 155 160 165 170 175 180 E

N 50

TROPICAL STORM TIP
 BEST TRACK TC-23W
 08 SEP-14 SEP 89
 MAX SFC WIND 50KT
 MINIMUM SLP 987MB

LEGEND
 \ / \ 6-HOUR BEST TRACK POSIT
 a b c SPEED OF MOVEMENT
 INTENSITY
 POSITION AT XX/0000Z
 oooooo TROPICAL DISTURBANCE
 oooooo TROPICAL DEPRESSION
 ----- TROPICAL STORM
 ----- TYPHOON
 ◆ SUPER TYPHOON START
 ◆ SUPER TYPHOON END
 ◆ EXTRATROPICAL
 ◆ SUBTROPICAL
 *** DISSIPATING STAGE
 F FIRST WARNING ISSUED
 L LAST WARNING ISSUED

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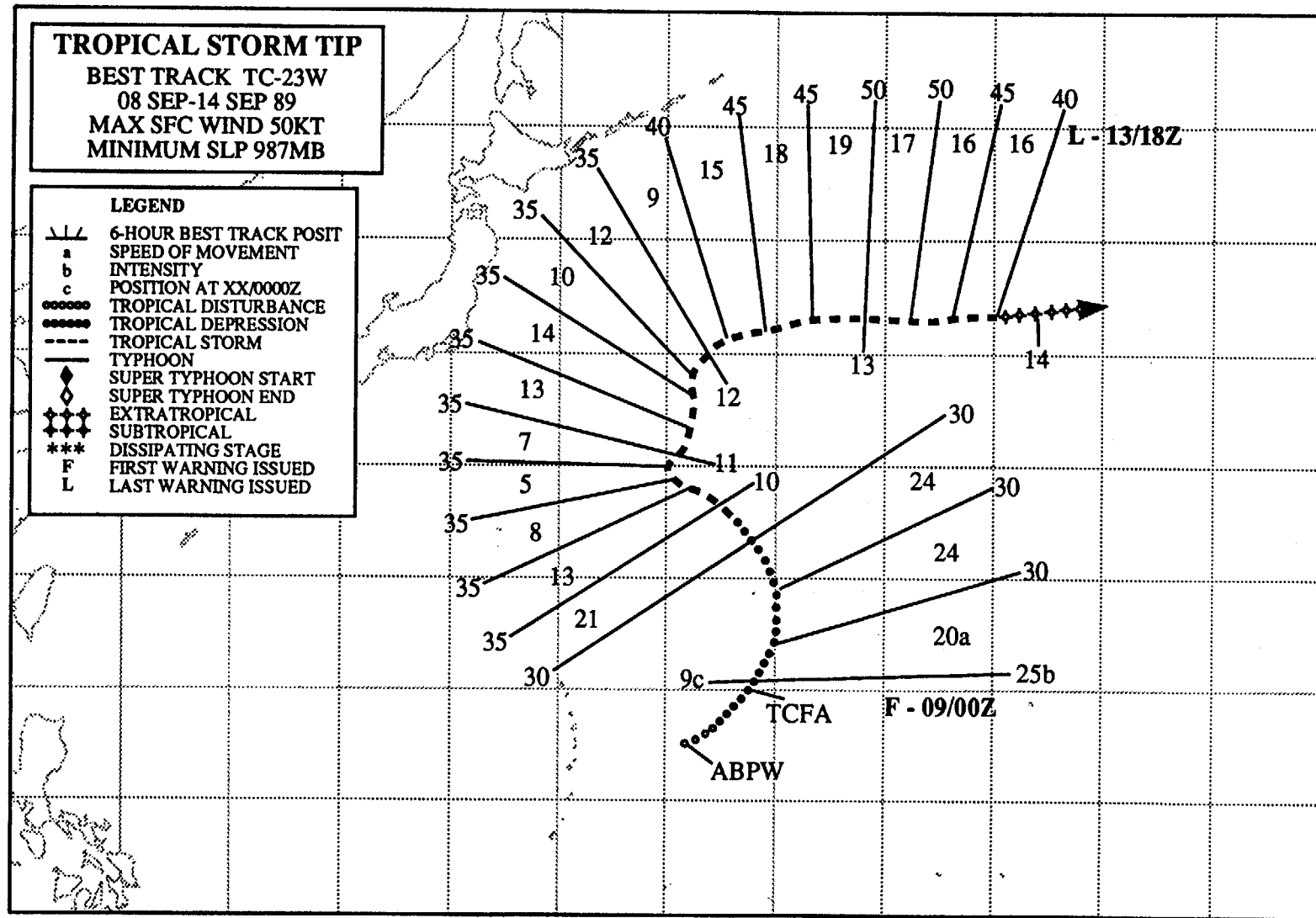
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N 10

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TROPICAL STORM TIP (23W)

Generating in early September at the eastern end of the monsoon trough, Tip executed an unusual track to the northeast, then recurved after moving northwestward around the subtropical ridge, and finally tracked eastward with the polar westerlies. Tip reached its peak intensity at 37° north latitude two days after recurvature.

Tip developed east of the Mariana Islands in an area of enhanced convection at the eastern-most extension of the southwest monsoon. At 080600Z, JTWC mentioned the area on the Significant Tropical Weather Advisory as having fair potential for further development. Increases in the amount, depth, and organization of the convection caused JTWC to issue a Tropical Cyclone Formation Alert at 082300Z. With synoptic data

supporting a closed low-level circulation and indicating 25 kt (13 m/s) sustained surface winds, JTWC issued the first warning on Tropical Depression 23W.

During the time that the depression moved rapidly northeastward, and then northwestward, the "spin-up" of the system was slow, partially due to the large size of the vortex. By the time Tip reached the axis of the subtropical ridge and slowed late on 10 September, the bulk of the supporting convection from the monsoonal flow had moved away to the east and north, and had dissipated, leaving only a small ragged patch of dense overcast near the partially exposed low-level circulation center.

At 110600Z, Tip (Figure 3-23-1) began

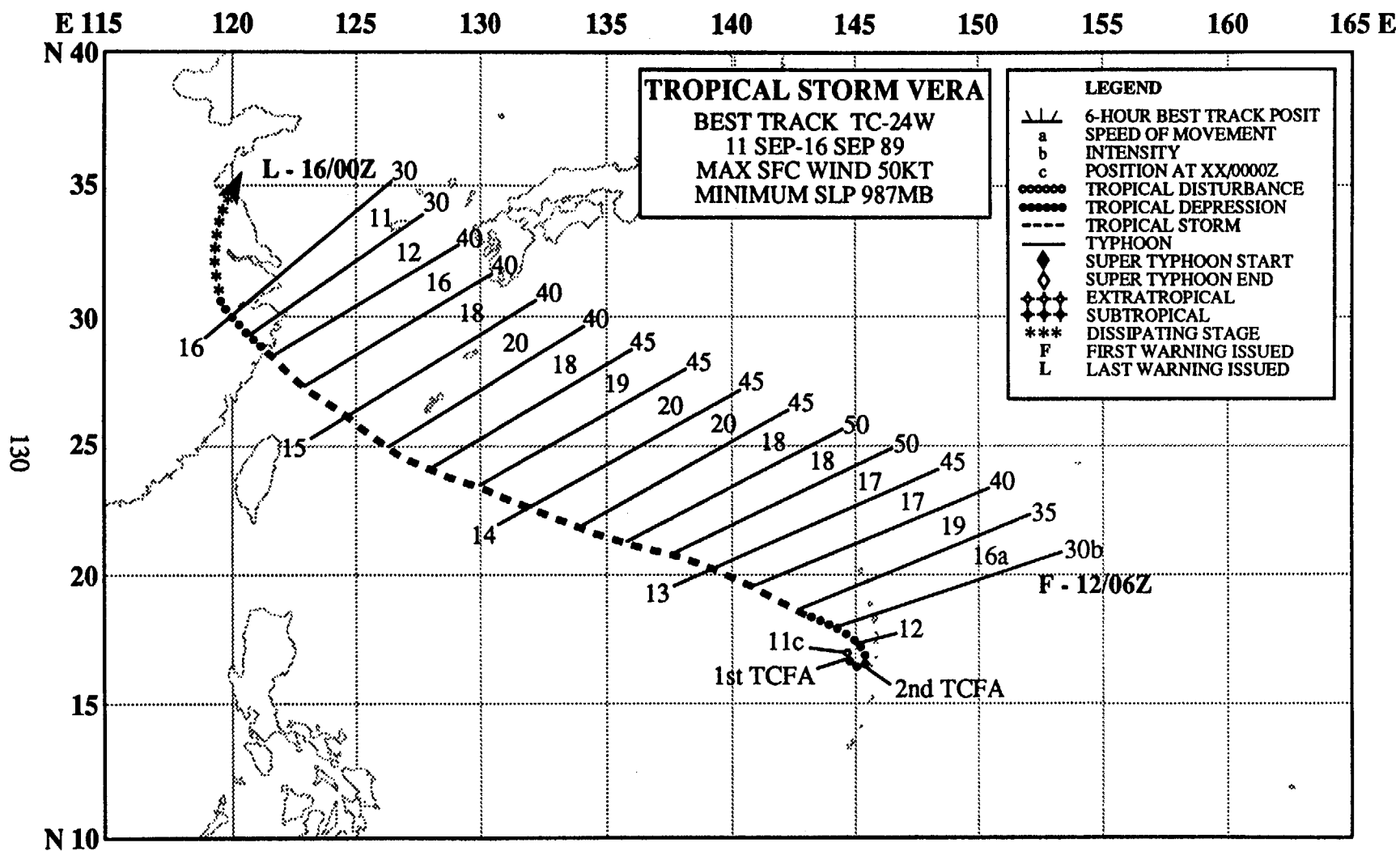


Figure 3-23-1. Tip accelerates to the northeast and begins recurving 400 nm (640 km) north-northeast of Minami Tori-shima (110324Z September NOAA visual imagery).

to accelerate to the north-northeast. During the next 18 hours, Tip appeared to be undergoing extratropical transition, but, at 120000Z, the tropical cyclone regained enough of its central convection to maintain its warm core. This additional translational effect from the acceleration assisted Tip in reaching its peak intensity of 50 kt (26 m/sec) at 130000Z.

During the early morning hours of the 13 September, Tip's convection tracked south-southeastward with the upper-level flow. Daylight satellite imagery revealed that the low-level circulation was well to the north of the convection. At 131800Z, JTWC issued the final warning on Tropical Storm Tip and passed warning responsibility for the extratropical gales to the Naval Western Oceanography Center at Pearl Harbor, Hawaii.

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TROPICAL STORM VERA (24W)

The third tropical cyclone in September, Vera generated north of Guam. After some initial erratic motion, the cyclone moved on a west-northwestward track, threatened Okinawa, and made a devastating landfall just south of Shanghai.

Vera generated in an area of low-level convergent flow in the monsoon trough approximately 250 nm (465 km) north of Guam. Persistent convection had not been observed with this system prior to 101200Z. By then, however, the combination of persistent convection, a preexisting low-level circulation center, and sea-level pressures below 1004 mb triggered JTWC to issue the first Tropical Cyclone Formation Alert at 110430Z. Both satellite imagery and synoptic data indicated efficient outflow over the low-level circulation center suggesting good potential for further

development. JTWC reissued the Alert at 111500Z as the disturbance moved to the southeast, and out of the original Alert box.

After the initial erratic motion, the convection organized around the circulation center, and the cyclone settled into a track to the west-northwest. JTWC issued the first warning on Tropical Depression 24W at 120600Z. Moving into increased steering flow along the southern side of the subtropical ridge, the tropical cyclone increased its translational speed and continued to intensify. At 121200Z, JTWC upgraded the depression to Tropical Storm Vera.

Due to two impinging TUTT cells, which constricted the efficiency of its upper-level outflow, one to the northwest and one to the northeast, Vera (Figure 3-24-1) intensified

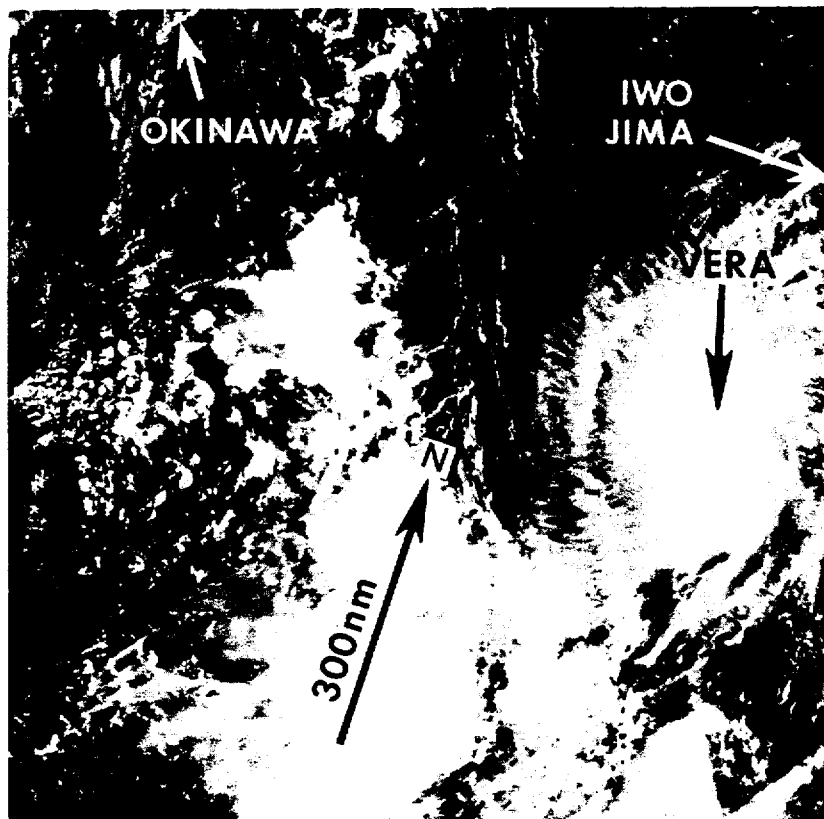


Figure 3-24-1. Convection flares shortly before Vera reaches its peak intensity (130042Z September DMSP visual imagery).

slowly, reaching only a peak intensity of 50 kt (26 m/sec) at 130600Z. On 14 and 15 September, as the tropical cyclone accelerated to a forward speed of 20 kt (10 m/sec), it started to weaken due to strong vertical wind shear. Vera passed 100 nm (185 km) southwest of Okinawa and maintained tropical storm intensity until after it made landfall approximately 150 nm (240 km) south of Shanghai. At 151800Z, the cyclone was downgraded to a tropical depression. JTWC

issued the final warning at 160000Z, and the system dissipated over land 18 hours later. No damage reports were noted from Okinawa, however, press releases from China cited Vera as the most powerful cyclone to hit the low-lying Zhejiang province in southeastern China in decades. Estimates ran as high as 500 fatalities, 700 injured and hundreds missing. Heavy rains reportedly caused extensive flooding and crop damage.

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E 115 120 125 130 135 140 145 150 155 160 165 E
N 50

TYPHOON WAYNE
BEST TRACK TC-25W
16 SEP-21 SEP 89
MAX SFC WIND 65KT
MINIMUM SLP 976MB

45

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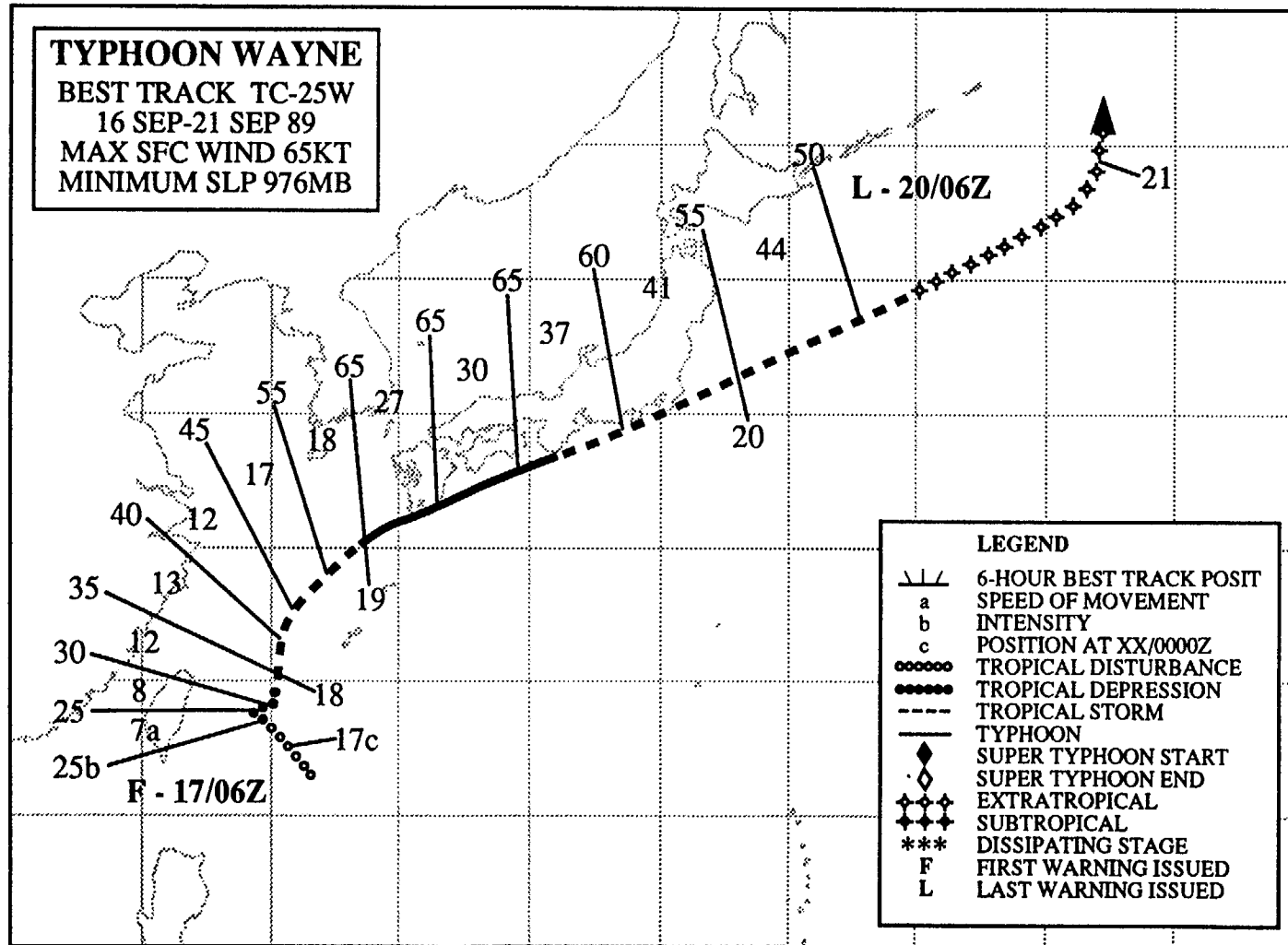
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TYPHOON WAYNE (25W)

The last of four tropical cyclones to develop in September, Wayne was also the last tropical cyclone of 1989 to affect Japan. It was unique in that it intensified after recurvature. Wayne caused considerable destruction, mudslides and some deaths in Japan.

About 24 hours after Tropical Storm Vera (24W) had dissipated over eastern China, the first warning on Tropical Depression 25W was issued at 170600Z indicating maximum sustained winds of 25 kt (13 m/sec). The depression formed approximately 300 nm (555 km) southwest of Okinawa and was expected to continue on a northwestward track into China before it could reach tropical storm intensity. JTWC issued a second Tropical Depression Warning at 171800Z. At that time, the six-hour

movement was thought to have been to the west; however, detailed post-analysis indicated that the system had, in fact, turned northward. The turn to the north as well as further intensification became evident by 180000Z. The depression was upgraded to Tropical Storm Wayne and was forecast to track northeast through central Honshu and dissipate near Tokyo.

JTWC forecasters maintained that forecast scenario until 181200Z, when they took the track more northward into the Sea of Japan. This change in thinking was based on the persistent northward movement and the NOGAPS prognostic series that indicated a deepening low in the Sea of Japan would attract the system. JTWC's prognostic reasoning

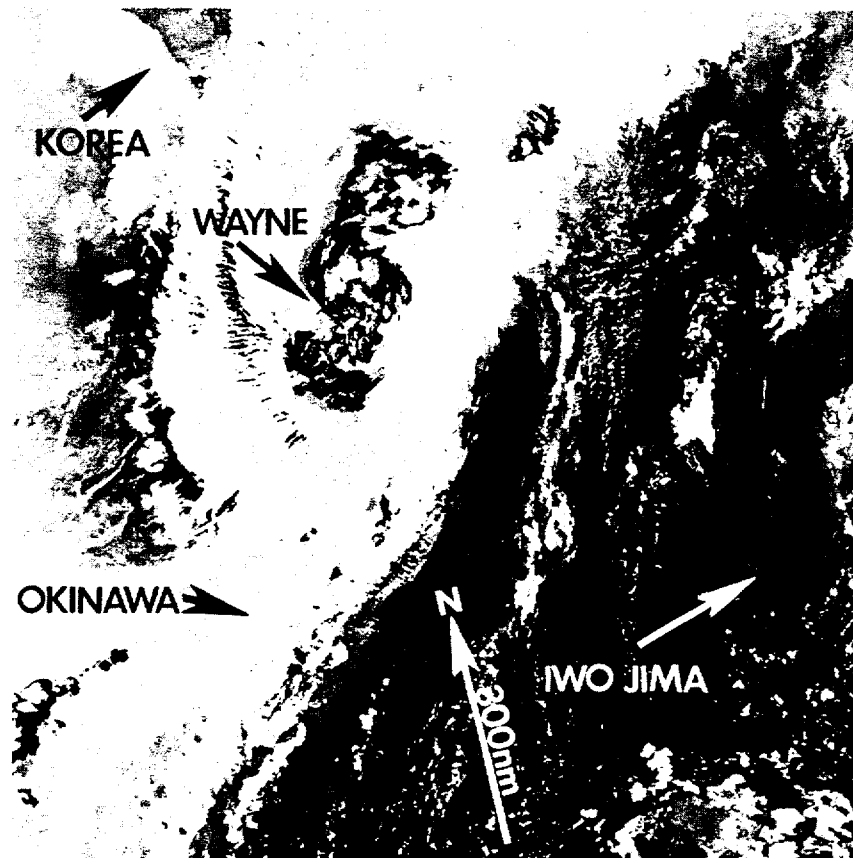


Figure 3-25-1. Typhoon Wayne along the southern coast of Japan (190932Z September DMSP enhanced infrared imagery).

discussed the possibility of the system being caught by the approaching frontal system and remaining south of Japan. The strong vertical wind shear present east of Korea was expected to prevent Wayne from exceeding tropical storm intensity.

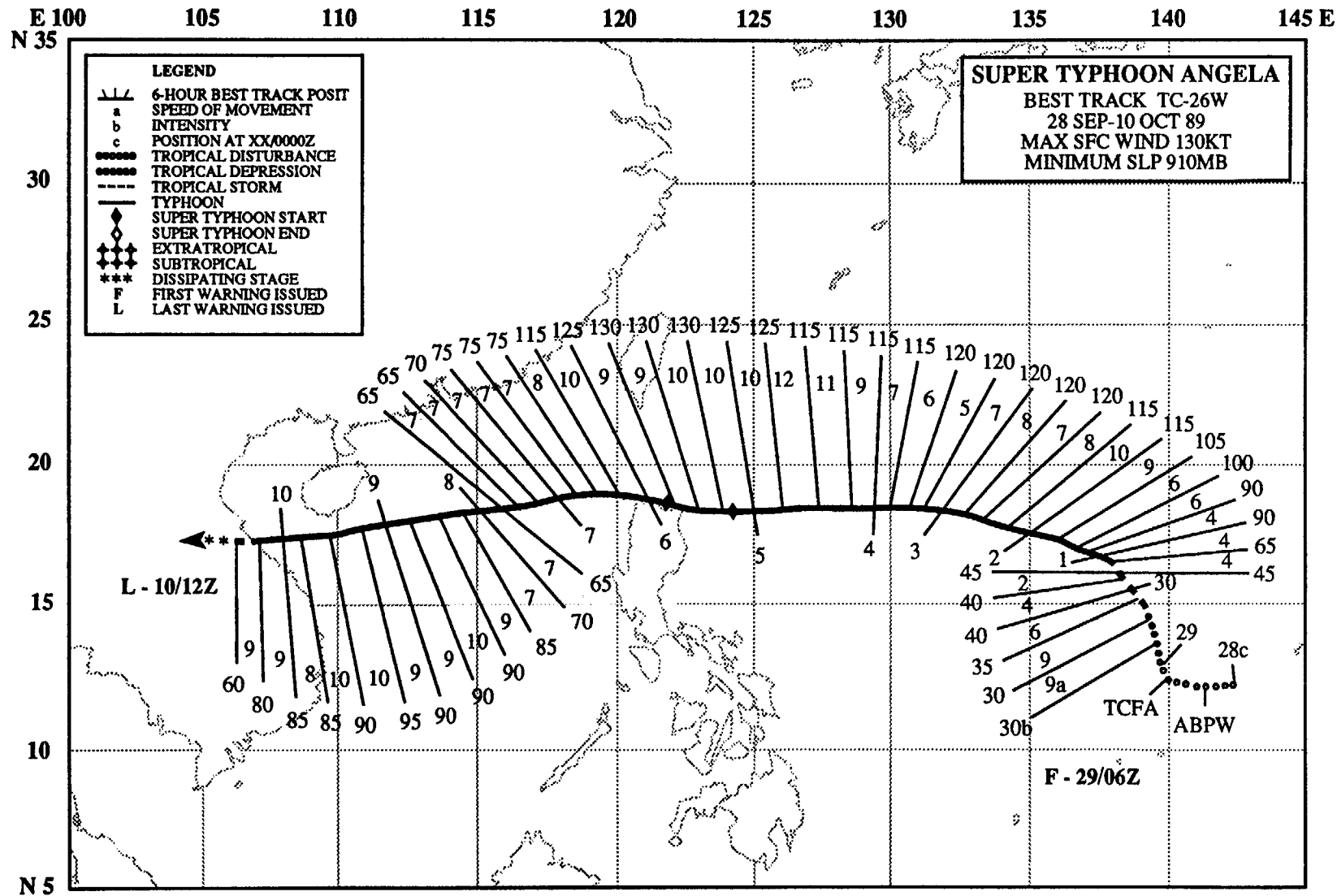
Surprisingly, satellite imagery at 181800Z indicated Wayne had apparently developed an eye. The warning was amended four hours later as subsequent satellite imagery confirmed the presence of an eye and further intensification. At 190000Z, Wayne was upgraded to a typhoon. While not a common occurrence, intensification after recurvature can occur when a tropical cyclone recurves at relatively low latitudes; and the jet stream provides an efficient outflow channel. A favored time for such intensification (Guard, 1983) is during the fall when warm sea surface temperatures extend into higher latitudes.

Significant acceleration started at 190000Z, and Wayne (Figure 3-25-1) was downgraded to a tropical storm at 191800Z.

Fortunately for Japan, as Wayne accelerated, the translational speed diminished the maximum sustained wind speeds in the northwest quadrant, which was over land. Yokota AB, Japan (WMO 47642), experienced maximum sustained winds of 14 kt (7 m/sec) with a peak gust to 19 knots (10 m/sec), even though Wayne passed only 45 nm (85 km) to the southeast. Tateyama (WMO 47672), southeast of Yokosuka at the mouth of Sagami Bay, took a direct hit from Tropical Storm Wayne, and after the storm passed, the station recorded 60 kt (31 m/sec) sustained winds with gusts to 84 kt (43 m/sec). Heavy rains caused flooding and mudslides. News reports indicated at least seven people died and over 4000 homes were flooded.

By 191800Z, Wayne's translational speed had increased to 40 kt (74 km/hr) and the system began to transition into an extratropical low. JTWC issued the final warning on Wayne at 200600Z as it underwent a compound transition (Brand and Guard, 1978) and merged with a cold-core low east of Hokkaido.

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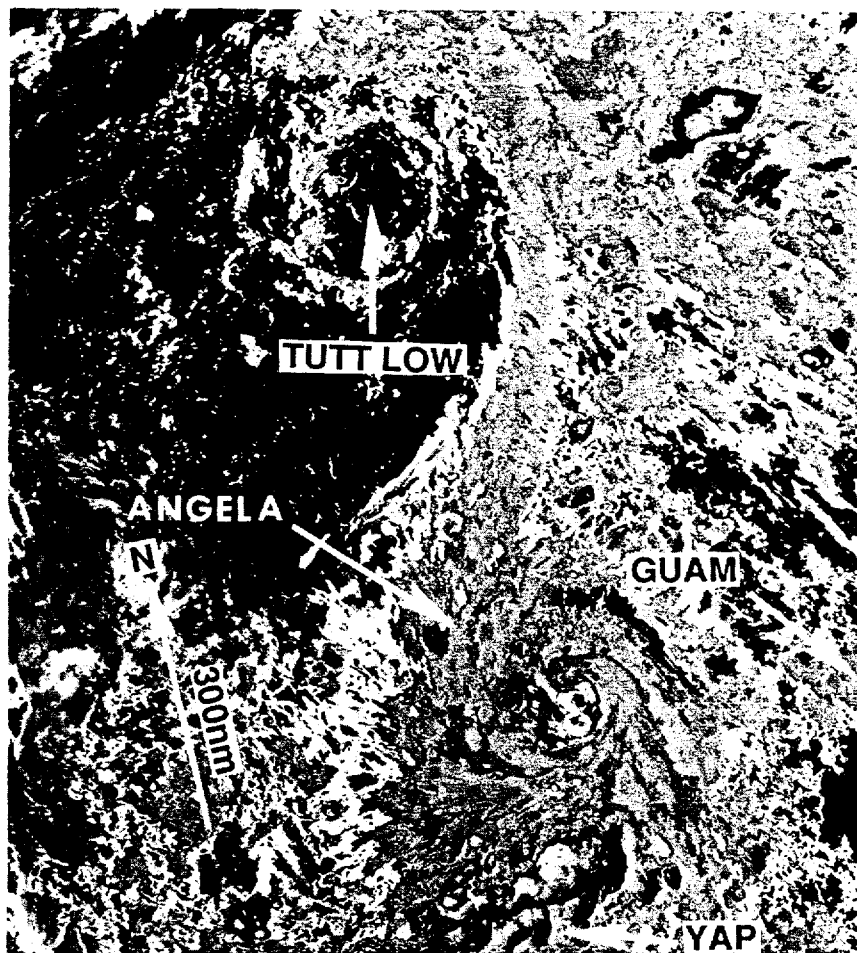


SUPER TYPHOON ANGELA (26W)

Angela was the first of three tropical cyclones to form in the monsoon trough during the three-day period 29 September to 2 October. It had the unique distinction of being in warning status longer than any other tropical cyclone in the western North Pacific this year — 12 days. From 29 September to 10 October, JTWC issued a total of 46 warnings on Angela. Angela also was one of five tropical cyclones to reach super typhoon intensity in 1989. Developing south of Guam, Angela tracked slowly westward and struck northern Luzon with super typhoon intensity causing a large number of casualties and wide spread destruction. It then continued into the South China Sea, where it reintensified, finally making landfall in central Vietnam.

During late September, the monsoon trough, located near 10° north latitude, became very active after a week of little convective activity. On 26 September an area of convection developed in the western Caroline Islands. The disturbed weather persisted for two more days, and was added as a suspect area to the 280600Z Significant Tropical Weather Advisory. As the disturbance moved to the southeast side of a Tropical Upper Tropospheric Trough (TUTT) cyclone, it organized rapidly. This resulted in the issuance of a Tropical Cyclone Formation Alert at 281730Z. The enhanced upper-level outflow from the TUTT low aided further development, and the first warning on Tropical Depression 34W (Figure 3-26-1) was issued at 290600Z.

Figure 3-26-1. Angela just after the initial warning was issued. The TUTT low northwest of Angela is enhancing upper-level outflow and divergence (290904Z September DMSP enhanced infrared imagery).



The depression was upgraded to Tropical Storm Angela at 291800Z. Angela initially tracked northwestward, as it developed, influenced by a mid-latitude short wave to the northwest. At 010600Z, the short wave had moved to the east, and Angela started tracking westward along the south side of the subtropical ridge. In the meantime as the short wave approached, Angela developed dual outflow channels and rapid intensification occurred. Angela intensified from 45 kt (23 m/sec) to 90

kt (46 m/sec) during the period 301200Z to 010000Z, reaching typhoon intensity at 301800Z. After 010000Z, intensification was slower as Angela lost the outflow channel to the north. It wasn't until four days later, at 050600Z, that Angela (Figure 3-26-2) was upgraded to a super typhoon.

Between 051500Z and 060300Z, Angela skirted along the northern coast of Luzon and was downgraded to a typhoon at

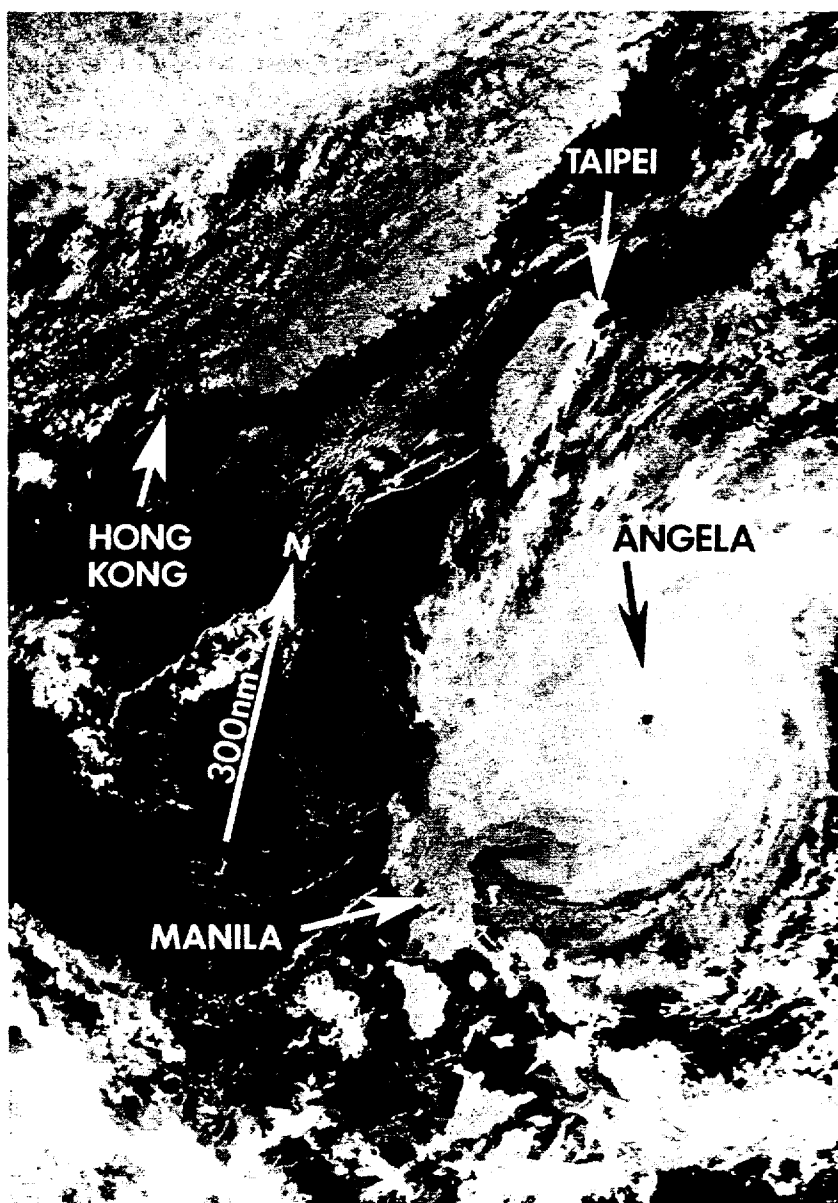
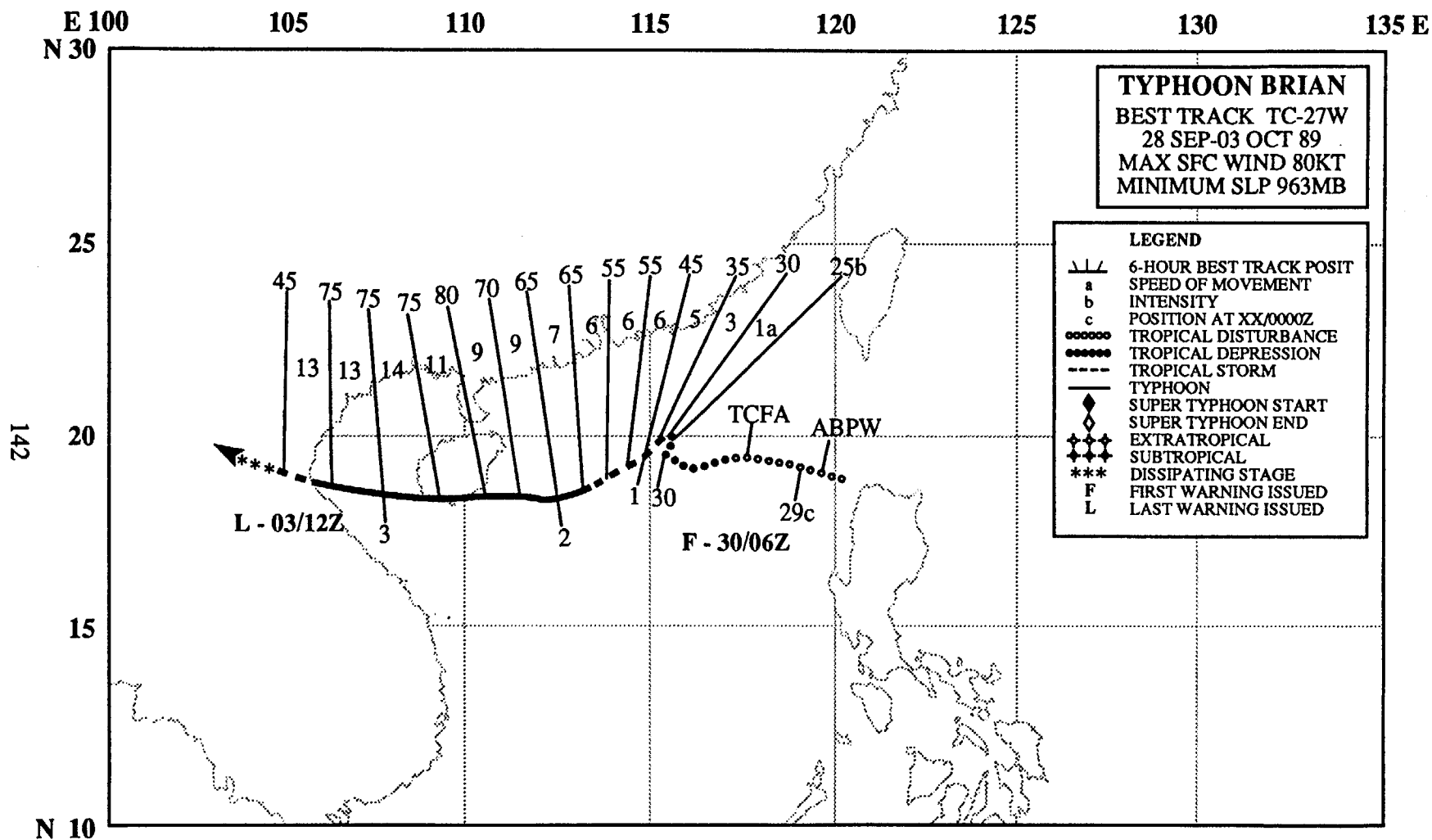


Figure 3-26-2. Super Typhoon Angela at peak intensity just prior to hitting northern Luzon (050558Z October NOAA visual imagery). Note: The spot in the eye is a blemish on the original transparency.

060600Z as it moved into the South China Sea. News reports from the Philippines indicated that the death toll from Angela was 62, mostly drowning victims, with 50 others missing and 21 injured. The high winds and heavy rains triggered flooding and caused heavy damage to crops and infrastructure. Angela destroyed more than 22,000 houses and sent 118,000 people fleeing to evacuation centers.

In the South China Sea, the typhoon started to track west-southwestward with high pressure building over China. As vertical wind shear weakened, Angela reintensified reaching 95 kt (49 m/sec) at 090600Z. Interacting with the topography of Hainan, the typhoon weakened before it moved inland in central Vietnam. At 100600Z, Angela made landfall approximately 30 nm (55 km) north of Hue, Vietnam and the last warning followed at 101200Z.



TYPHOON BRIAN (27W)

Typhoon Cecil (04W) in May and Typhoon Brian in late September and early October were the only tropical cyclones of the year to develop and spend their entire lifetimes within the confines of the South China Sea.

As Super Typhoon Angela (26W) developed over the Philippine Sea, the monsoon trough became active across the South China Sea from western Luzon to Vietnam. A broad area of moderate convection developed in the trough and was first mentioned on the 280600Z September Significant Tropical Weather Advisory as a fair suspect area about 390 nm (720 km) southeast of Hong Kong. The satellite

signature indicated a well defined upper-level anticyclone, but a weak surface circulation with very little deep convection.

The strong upper-level anticyclone persisted for the next 24 hours and synoptic data indicated that the low-level cyclonic circulation had intensified, prompting the issuance of a Tropical Cyclone Formation Alert at 290830Z. The circulation moved slowly westward along the southern side of the mid-tropospheric subtropical ridge. At 300000Z, the ridge weakened and the disturbance became quasi-stationary 195 nm (360 km) southeast of Hong Kong.

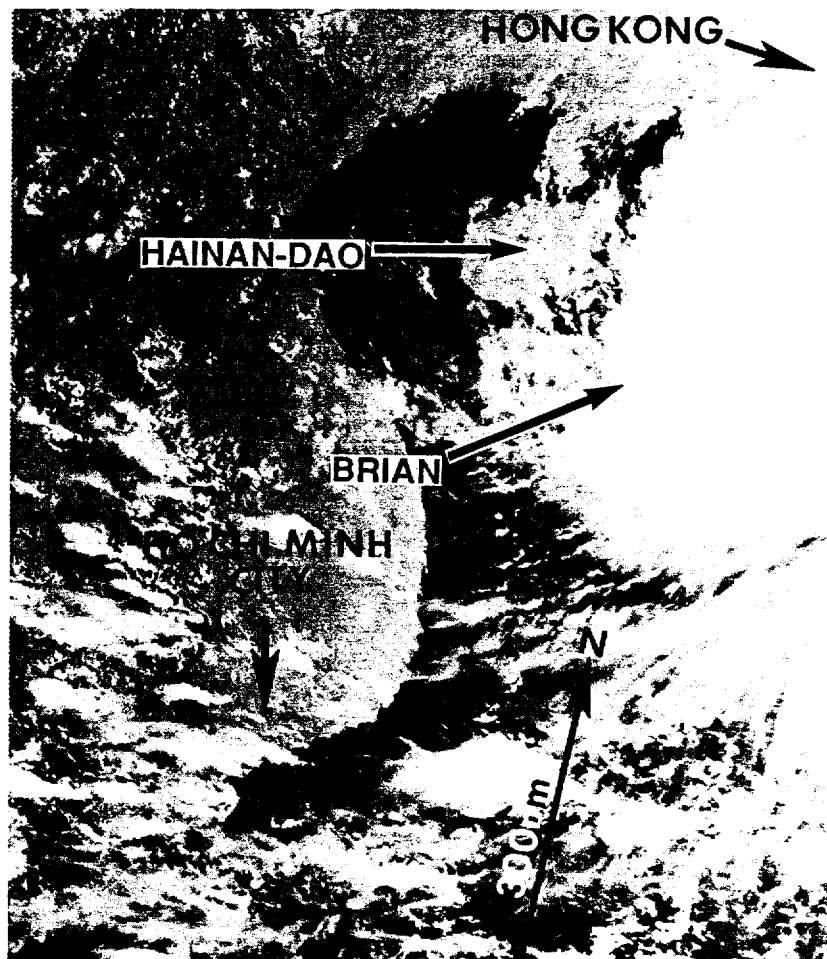


Figure 3-27-1. Tropical Storm Brian tracks toward Hainan (010641Z October NOAA visual imagery).

Over the next six hours, the disturbance drifted northward in an area of weak mid-level steering flow. As JTWC did not expect the depression to intensify during the next 48 hours, a 36-hour Tropical Depression Warning was issued for Tropical Depression 27W at 300600Z. Shortly thereafter, the subtropical ridge strengthened to the north and the depression moved west-southwestward and intensified. Brian (Figure 3-27-1) was upgraded to tropical storm intensity at 301800Z and to typhoon status 24 hours later when it was 240 nm (445 km) southwest of Hong Kong.

On 2 October at 0000Z, Brian (Figure 3-27-2) settled on a westward course and increased its forward speed to 9 kt (17 km/hr). At 021200Z, the typhoon reached a peak

intensity of 80 kt (41 m/sec) approximately 20 nm (35 km) off the southeast coast of Hainan Island. Three hours later the cyclone crossed the extreme southern coast of Hainan and weakened to 75 kt (39 m/sec). News releases from the area reported that at least 31 people perished and 500 were injured. In addition, Brian damaged an estimated 190,000 acres (77,000 hectares) of rice.

After mauling Hainan, the typhoon maintained its westward course and 75-kt (39-m/sec) intensity until it made landfall near Vinh, Vietnam. JTWC issued its last warning on Brian at 031200Z. The convection continued westward into the mountains of Vietnam and dissipated the next day.

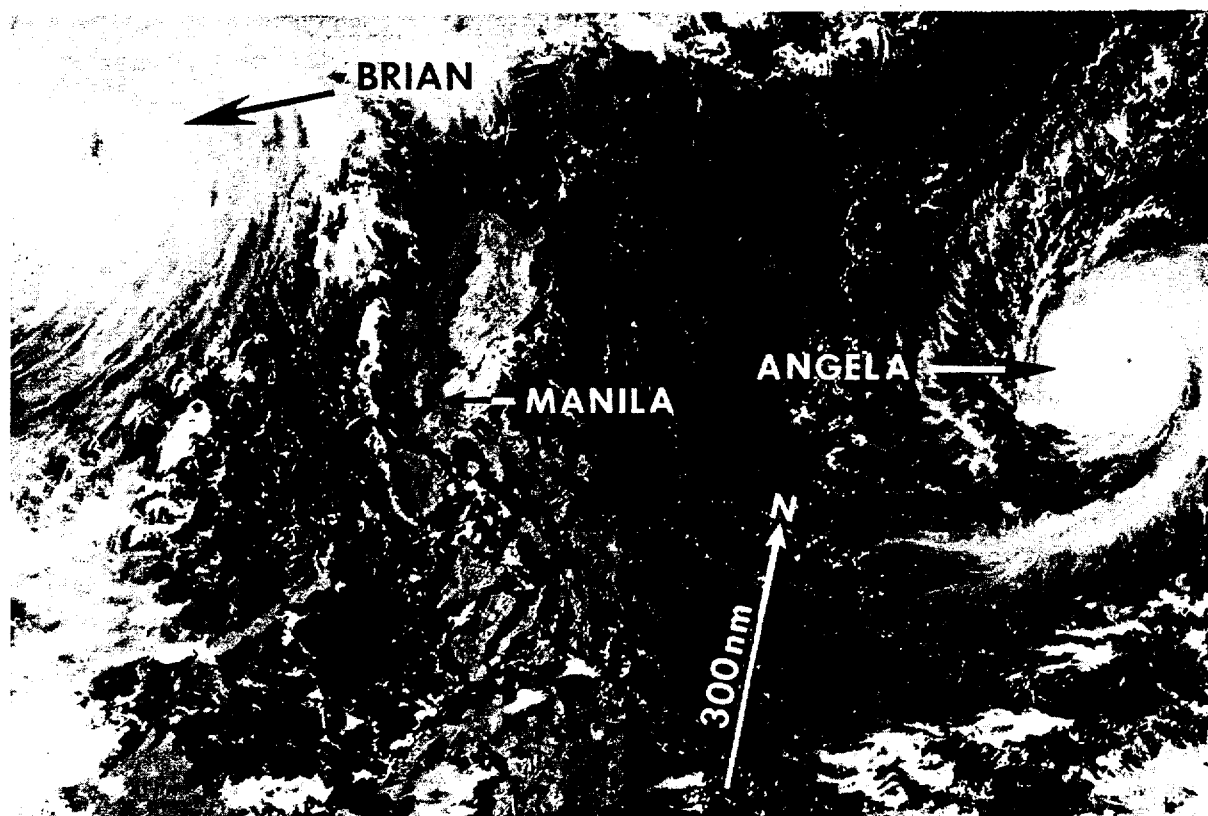
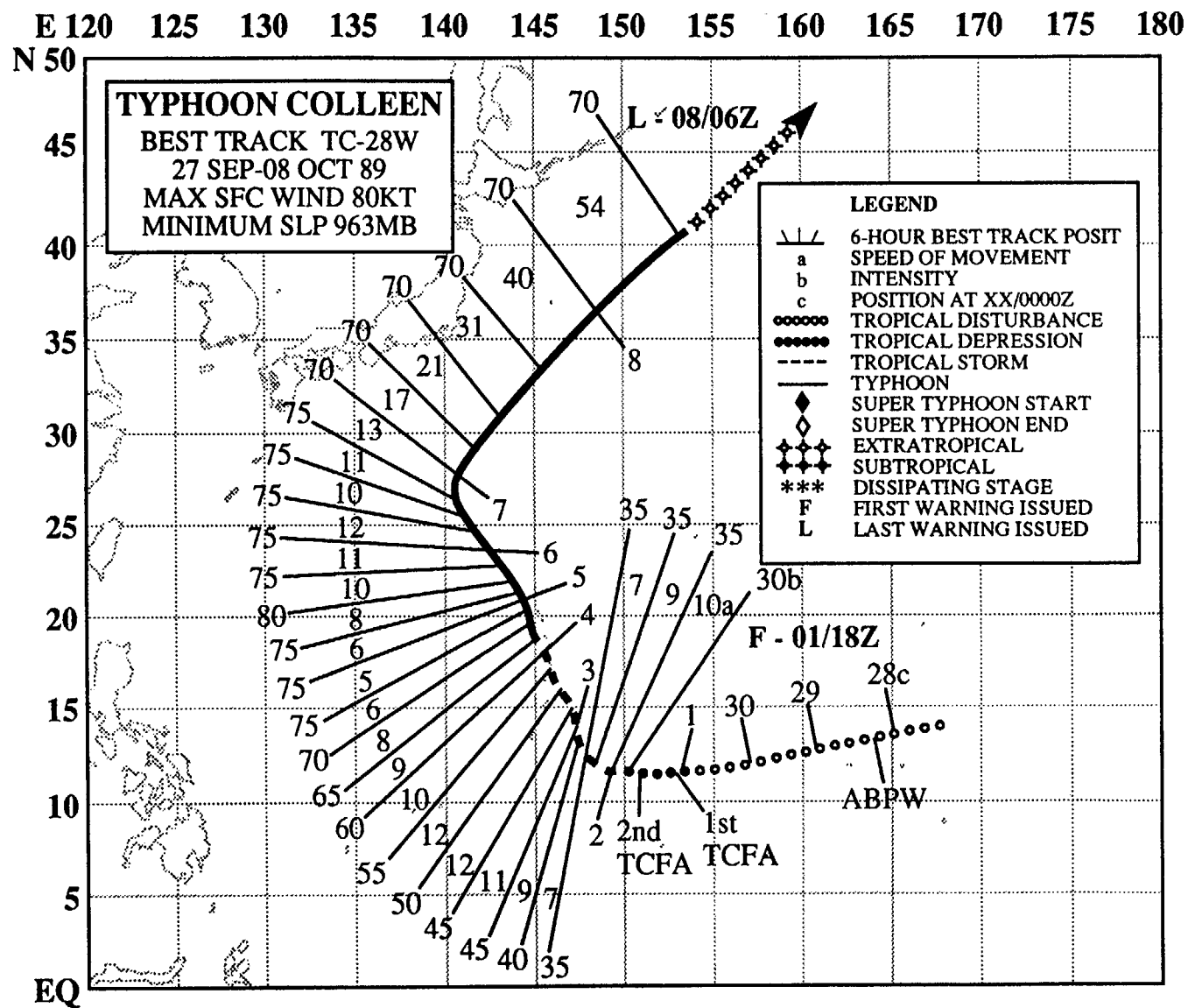


Figure 3-27-2. Typhoons Angela (26W) and Brian. Angela's intensity of 115 kt (59 m/sec) is almost twice that of Brian's (020100Z October DMSP visual imagery).

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TYPHOON COLLEEN (28W)

Forming just north of the Marshall Islands, Colleen passed through the northern Mariana Islands before recurving south of Japan. The tropical cyclone maintained typhoon intensity until it completed extratropical transition. Also, Colleen threatened PACEX 89 — the largest US Navy exercise conducted in the Pacific since the Korean War. Colleen underscored the difficulty of tracking poorly organized systems with only nighttime infrared satellite imagery, but also showed the value of the microwave imager data as a tool to help locate these systems.

In the last week of September, Super Typhoon Angela (26W) was forming in the Philippine Sea and Typhoon Brian (27W) in the South China Sea. A deep trough penetrated into the tropical northwestern Pacific near the dateline. An area of cloudiness formed at the base of the trough on 23 September and moved slowly southwestward toward the Marshall Islands. In the data sparse area there were no

indications of a surface circulation until 271200Z when pressure falls and wind shifts throughout the northern Marshall Islands reflected the passage of a surface circulation or a tropical wave. JTWC first identified the disturbance as a suspect area on the Significant Tropical Weather Advisory at 280600Z. The disturbance was tracked on the Advisories for the next three days until a Tropical Cyclone Formation Alert was issued at 010030Z October. At that time, based on satellite imagery, the disturbance was analyzed as moving west-northwestward at 15 kt (28 km/hr). Forecasters noted that gradient-level winds at Guam (WMO 91217) had slowly veered from the south-southeast to the west-northwest from 290000Z September until 010000Z October despite the presence of Tropical Storm Angela (26W) to the west of Guam.

The Alert was reissued at 011400Z when satellite analysts determined that the disturbance was moving westward at 9 kt (17

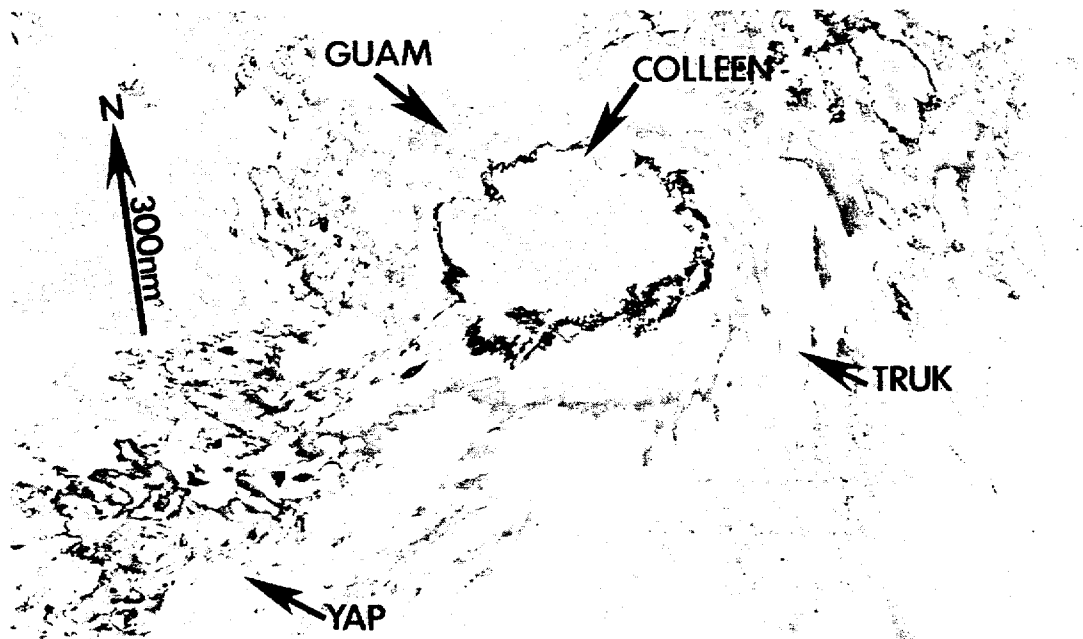


Figure 3-28-1. Tropical Storm Colleen approaching Guam (021159Z October DMSP enhanced infrared imagery).

km/hr). The first warning on Tropical Depression 28W followed at 011800Z after satellite imagery indicated the development of a central dense overcast. The depression was upgraded to Tropical Storm Colleen with the second warning at 020000Z. The forecasts for the initial five warnings called for the system to track south of Guam, however, the accompanying Prognostic Reasoning Messages discussed the possibility of a "stair step" in response to the passage of a short wave trough indicated by the NOGAPS prognostic series.

Tracking Colleen (Figure 3-28-1) became a problem during the night of 2 October. Earlier in the evening, a USAF contractor was installing a computer at Detachment 1, 1WW to process and display DMSP microwave imager information. Between 020800Z and 020900Z, microwave imager data from the 85-gigahertz channel was acquired and processed. These data were able to "see through" the high overcast clouds and the analyst could locate the center of the tropical storm and verify the positions obtained from the infrared channel. Subsequent nighttime infrared positions, without the benefit of the microwave data,

indicated that the system was moving west-northwestward in excess of 12 kt (22 km/hr). The 021200Z satellite fix placed the position of the storm within 100 nm (185 km) of Guam, but neither the weather radar at Andersen AFB nor the Air Traffic Control radar operated by the Federal Aviation Administration on Guam could confidently locate the center. Because of the contradictory information presented by the satellite fixes, the lack of central or banding features on radar, and the absence of falling pressures that should accompany a rapidly approaching system, the 021200Z warning position was based only partly on the satellite-derived position. In the post-analysis, the 021200Z satellite position was 96 nm (178 km) west of the final best track position. The average error of the eight infrared satellite fixes made during the night of 2 October was 68 nm (126 km) compared to the 20-nm (37-km) average error for the visual fixes on the 2 and 3 October. Warning number five, valid at 021800Z, was amended at 022300Z and relocated the position of the system to the north based on the first available visual satellite imagery. Also, at that time, 24-hour surface pressure falls at Saipan (WMO 91232) in-

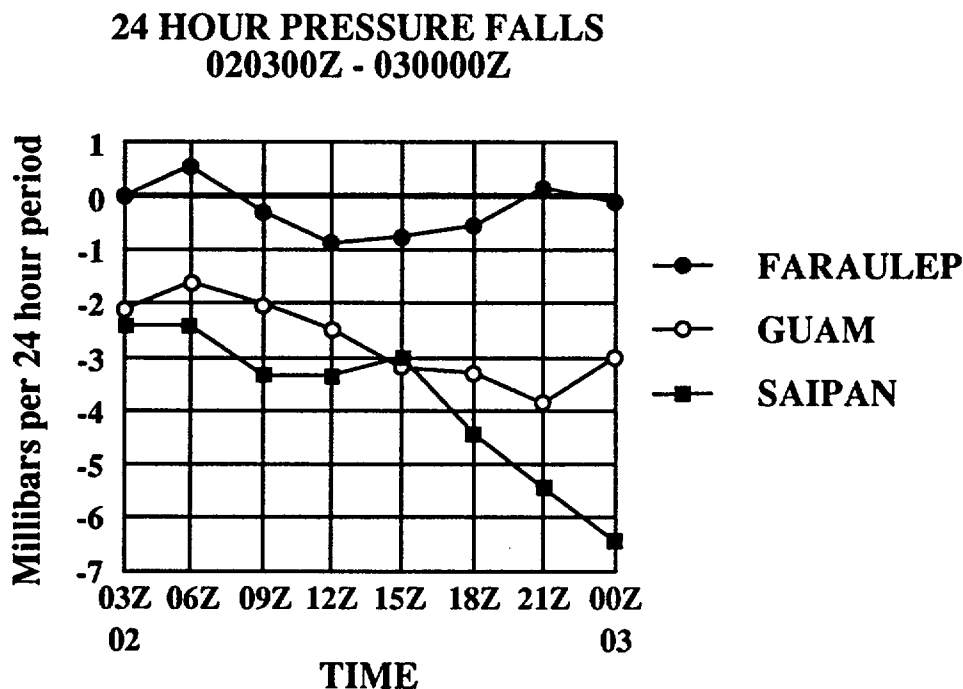


Figure 3-28-2. Twenty-four hour pressure falls at Guam, Saipan, and Faraulep from 020300Z through 030000Z.

creased while Guam (WMO 91212) and the Faraulep AMOS station (WMO 52005) indicated slowing trends (Figure 3-28-2). The relocated position indicated the system had tracked northwestward during the night and was moving towards a weakness in the subtropical ridge. JTWC's amended warning took the system near Saipan in 36 hours. Colleen would eventually pass 120 nm (220 km) to the east of Guam and 30 nm (55 km) to the northeast of Saipan. Colleen tracked northwestward through the northern Marianas (Figure 3-28-3) passing within 60 nm (110 km) of the islands of Pagan and Farallon de Pajaros -- both proposed sites for future Automated Meteorological Observing Stations (AMOS). Heavy rains during Colleen's passage caused widespread flooding on Guam.

Warning number 6, valid at 030000Z, called for the start of recurvature in the vicinity

of Iwo Jima near the 72-hour point. However, Colleen slowed to 5 kt (9 km/hr) on 5 October and recurvature was delayed until 061800Z. Subsequent warnings retained the recurvature scenario well south of Japan with significant acceleration to the northeast.

At 040600Z, satellite imagery indicated a partial eyewall, and Colleen was upgraded to a typhoon. The system reached peak intensity at 051200Z -- 210 nm (390 km) southeast of Iwo Jima -- and weakened only slightly as it headed for its recurvature point. Ships involved in PACEX 89 altered course to avoid any encounter with Colleen. After 061800Z, the tropical cyclone moved northeastward and weakened to 70 kt (36 m/sec). Colleen maintained its intensity but doubled its speed of movement to 21 kt (39 km/hr) during the next 18 hours, and almost doubled it again to 40 kt

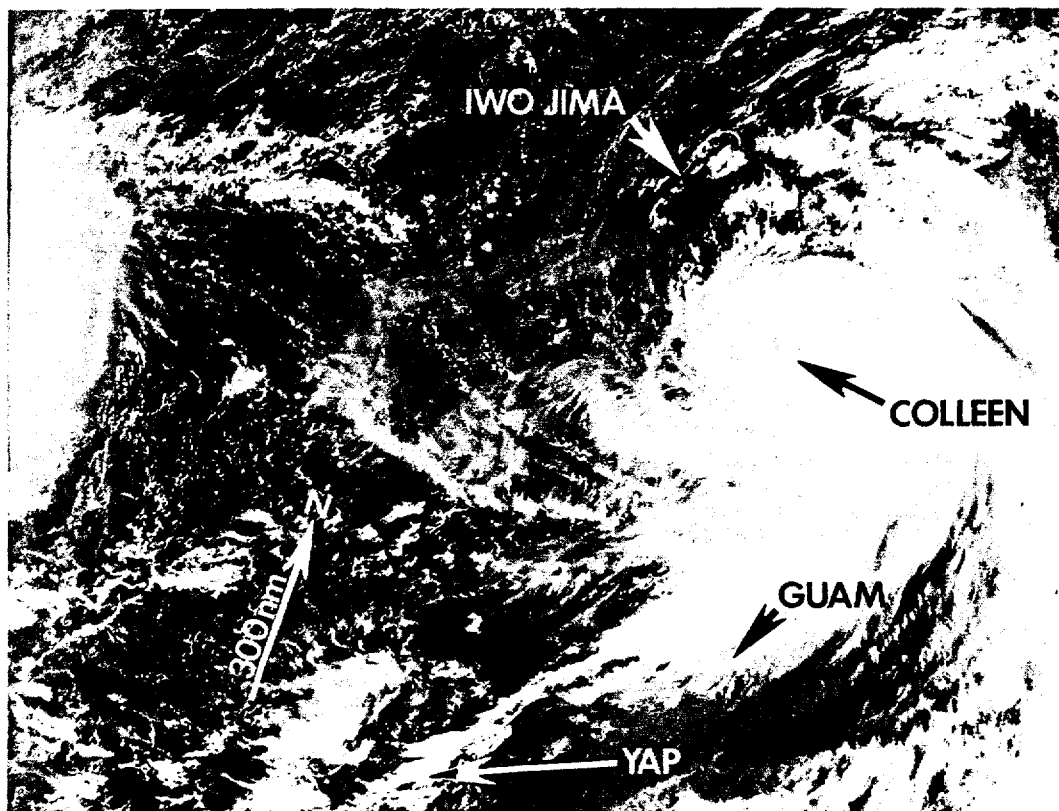


Figure 3-28-3. Typhoon Colleen leaving the northern Marianas. The cloud mass on the left is Typhoon Angela (26W) (042358Z October DMSP visual imagery).

(74 km/hr) during the following 12 hours.

JTWC issued its final warning at 080600Z (Figure 3-28-4) when Colleen was approximately 660 nm (1220 km) east of northern Honshu moving at 54 kt (100 km/hr) to

the northeast and still packing sustained winds of 70 kt (36 m/sec). It became one of the most intense extratropical cyclones of the year. In satellite imagery at 081200Z the extratropical remnants of Colleen were discernible near 46° north latitude.

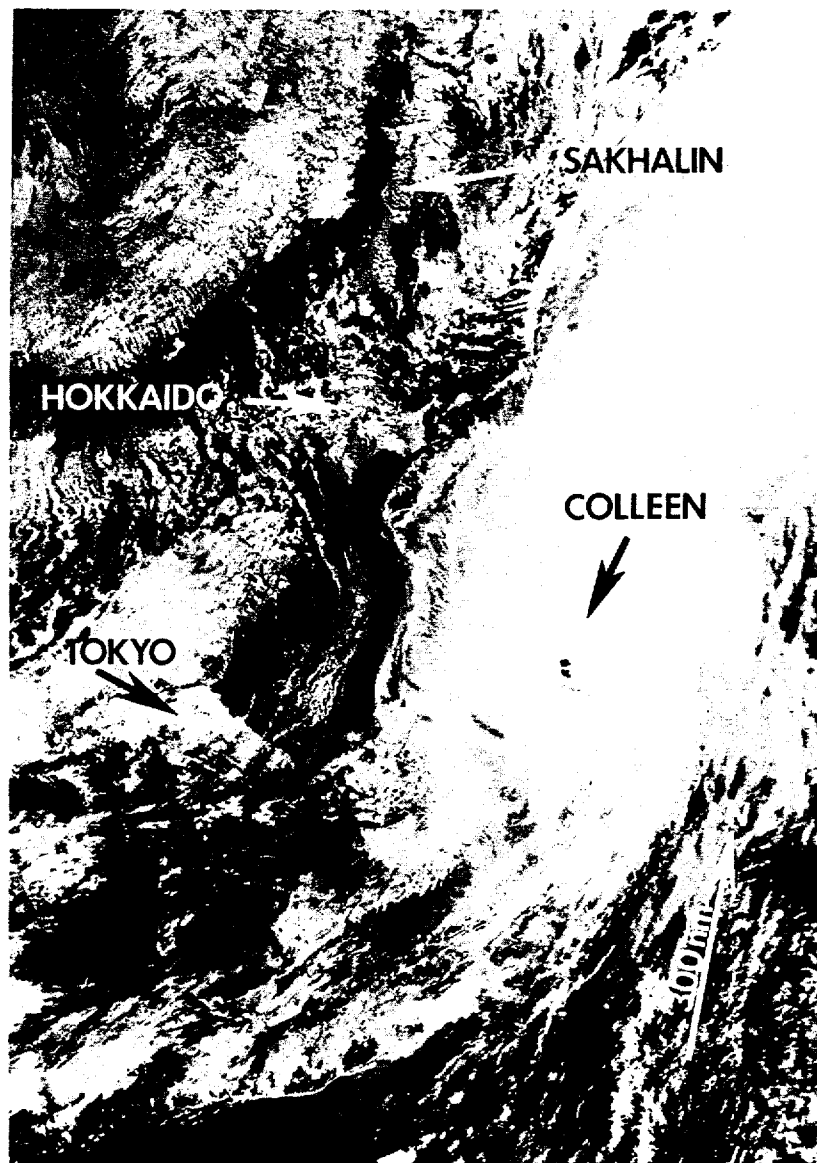
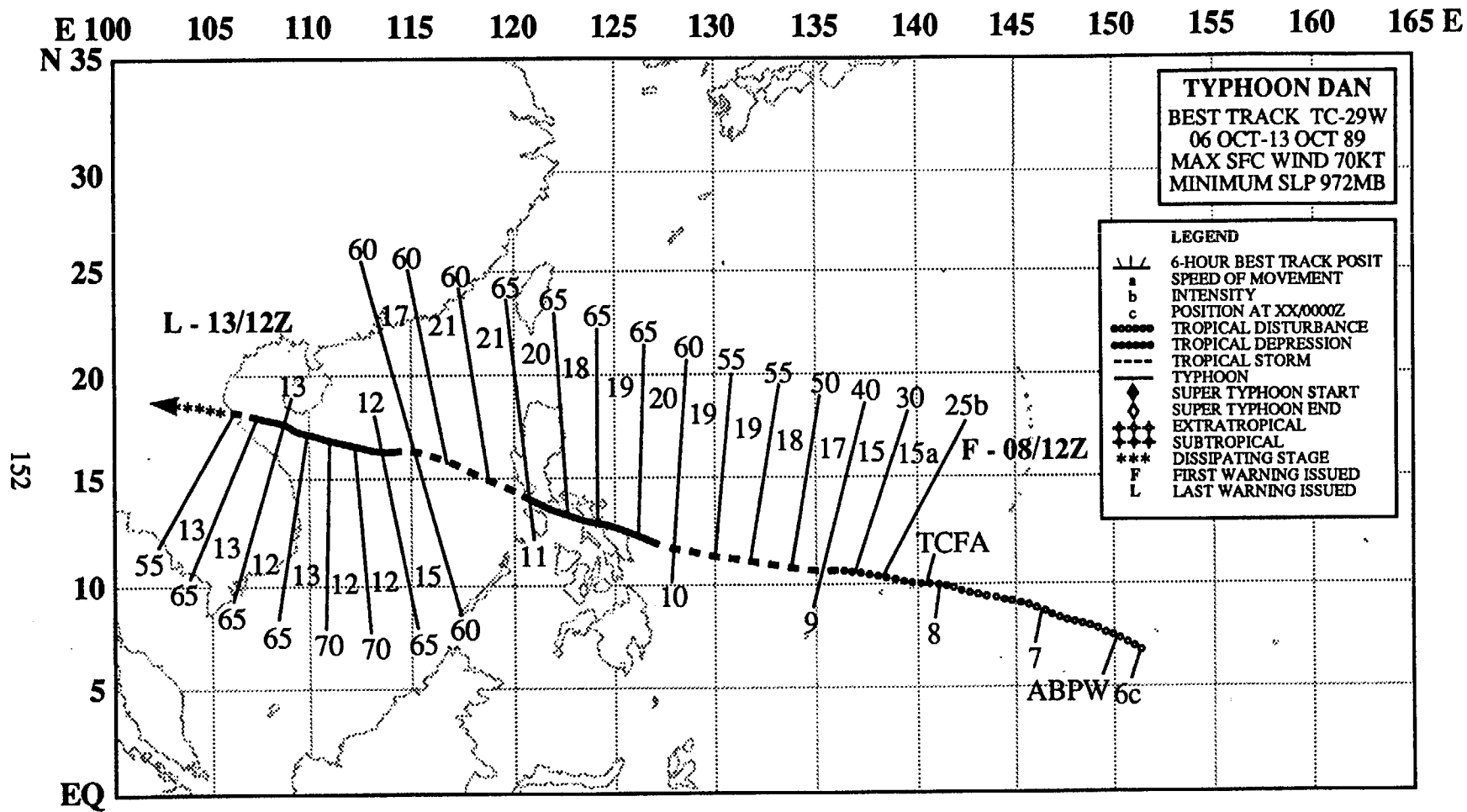


Figure 3-28-4. Typhoon Colleen undergoing extratropical transition (080344Z October NOAA visual imagery).

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TYPHOON DAN (29W)

Forming in October in the Caroline Islands near Truk, Dan followed a steady west-northwestward track and crossed the central Philippine Islands. Coming just days after Typhoon Angela's (26W) destructive passage through northern Luzon, Dan had a devastating effect on southern Luzon. The cyclone reintensified in the South China Sea and made landfall on the coast of central Vietnam where it caused more destruction.

On 6 October a disturbance formed in the monsoon trough near Truk in the central Caroline Islands. JTWC evaluated the weak low-level circulation center and its divergent flow aloft. On the Significant Tropical Weather Advisory at 060600Z, in light of strong vertical wind shear affecting the disturbance, JTWC classified it as having poor potential for development. After the disturbance persisted for another day, the potential was upgraded to fair. On 8 October, weaker vertical wind shear and the presence of a well-developed band of convection near the low-level circulation center led to the issuance of a Tropical Cyclone Formation Alert at 0330Z.

At 081200Z, JTWC issued the first warning on Tropical Depression 29W which was located 60 nm (110 km) northeast of Yap in the western Caroline Islands. Eighteen hours

later, the depression was upgraded to Tropical Storm Dan. The moderate flow south of the mid-level subtropical ridge axis kept the system on a 15- to 20-kt (28- to 37-km/hr) west-northwestward course toward the central Philippine Islands. Deep convection continued to improve with upper-level outflow efficient in all but the northwest quadrant, where it was restricted by the outflow from Typhoon Angela (26W). After outflow in the northwest improved and the eye became visible, Dan was upgraded to a typhoon at 100600Z.

At 101300Z, Typhoon Dan made landfall on the extreme southeastern coast of Luzon and later passed 20 nm (37 km) south of Manila's Ninoy Aquino International Airport (WMO 98429). The weather station reported sustained winds of 45 kt (23 m/sec) with gusts to 65 kt (33 m/sec). The strong winds rearranged some of the aircraft parked on the tarmac, blowing an Omani Boeing 707 and a Bangladesh presidential DC-10 into each other. Forty-eight nm (90 km) north of Manila, Clark AB (WMO 98327) received winds of 30 kt (15 m/sec) with gusts to 50 kt (26 m/sec) from 110100Z to 110400Z. Cubi Point NAS (WMO 98426), 40 nm (75 km) northwest of Manila, reported sustained winds of 40 kt (21 m/sec) with gusts to 75 kt (39 m/sec). From 100000Z to 120000Z Cubi Point reported 5 inches (125

mm) of rain, while Clark AB measured 3.5 inches (90 mm).

As Dan moved into the South China Sea, it lost its eye feature and weakened to tropical storm intensity at 110300Z (Figure 3-29-1). Tracking west-northwestward over the warm sea, the cyclone regained its convection, reformed its eye, and was again upgraded to a typhoon at 120000Z. Dan reached a peak intensity of 70 kt (36 m/sec) six hours later. The typhoon weakened slightly as it approached and passed 60 nm (110 km) to the south of Hainan Island. As Dan approached the coast of central Vietnam, increased mid- to upper-level shear elongated the cloud shield and weakened the system. Dan made landfall on the central coast of Vietnam at 131200Z, and at that time

JTWC issued a final warning. The circulation dissipated in the mountains and the disorganized convection continued westward into Laos.

Dan, despite being only a minimal typhoon, proved to be a very destructive one. In the Philippines the Department of Social Welfare reported at least 41 people killed; 16,185 houses damaged; and, 232,555 left homeless or without livelihoods. Electrical power was lost to 95% of Metropolitan Manila because of downed power lines; "brown-outs" continued for weeks afterward. In Vietnam, Dan ripped the roofs off buildings, downed communication lines, and flooded over 320,000 acres.

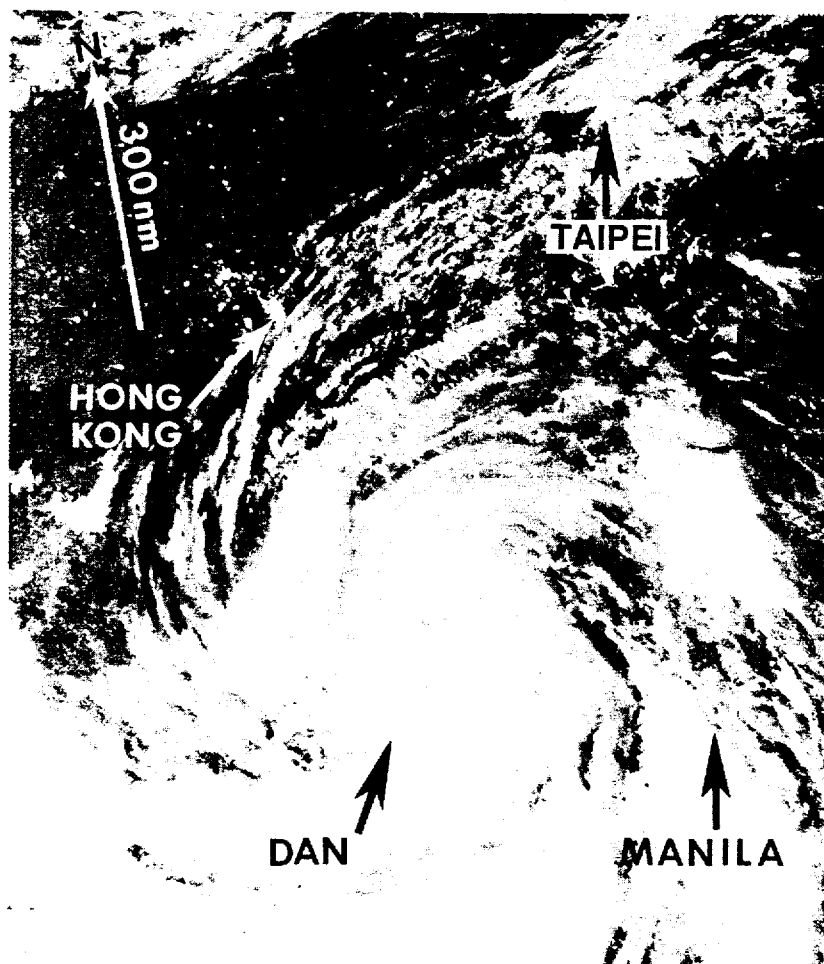


Figure 3-29-1. Moonlit photo of Typhoon Dan as it enters the South China Sea and the eye reforms (111348Z October DMSP visual imagery).

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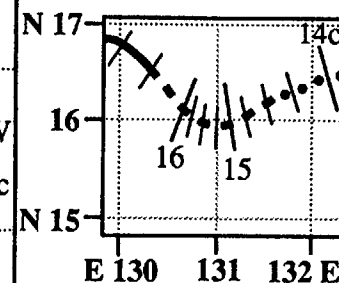
E 100 105 110 115 120 125 130 135 140 145 150 E

SUPER TYPHOON ELSIE

BEST TRACK TC-30W
13 OCT-22 OCT 89
MAX SFC WIND 140KT
MINIMUM SLP 898MB

LEGEND

- 6-HOUR BEST TRACK POSIT
- a SPEED OF MOVEMENT
- b INTENSITY
- c POSITION AT XX/0000Z
- ooooo TROPICAL DISTURBANCE
- ooooo TROPICAL DEPRESSION
- TROPICAL STORM
- TYPHOON
- ◆ SUPER TYPHOON START
- ◇ SUPER TYPHOON END
- ◆◆◆ EXTRATROPICAL
- ◆◆◆ SUBTROPICAL
- *** DISSIPATING STAGE
- F FIRST WARNING ISSUED
- L LAST WARNING ISSUED



DTG	SPEED	INTENSITY
14/00Z	15	30
14/06Z	4	30
14/12Z	2	35
14/18Z	2	35
15/00Z	2	40
15/06Z	3	45
15/12Z	1	50
15/18Z	1	55
16/00Z	1	60
16/06Z	4	70
16/12Z	4	90
16/18Z	6	100

30

25

20

15

10

5

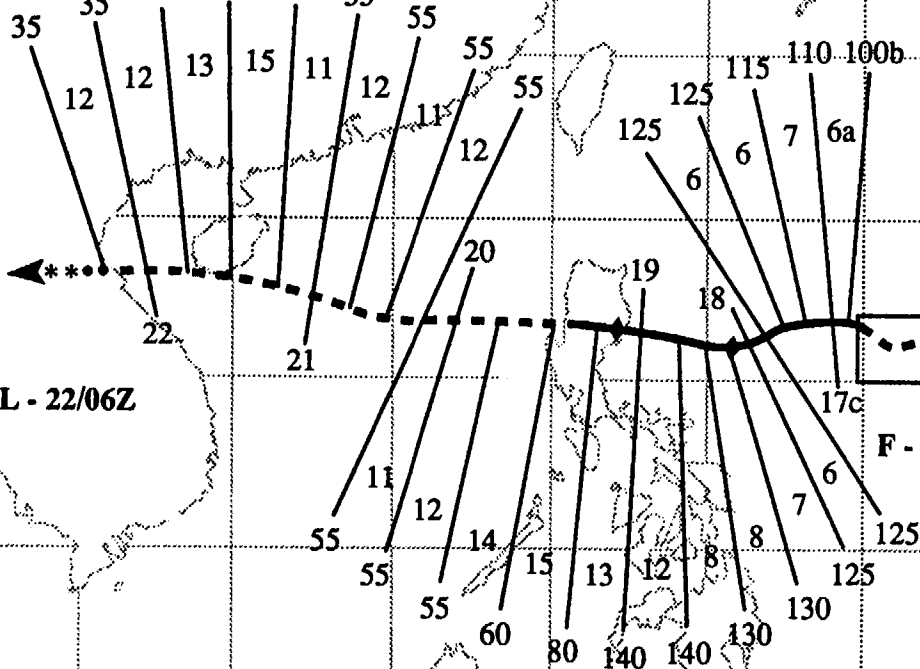
EQ

L - 22/06Z

F - 14/00Z

TCFA

ABPW



SUPER TYPHOON ELSIE (30W)

In the wake of Super Typhoon Angela (26W) and Typhoon Dan (29W), Super Typhoon Elsie became the third tropical cyclone to hit the Philippine Islands within 12 days. Elsie developed from a TUTT-induced wave in the easterlies and tracked westward throughout its life. In the Philippine Sea, Elsie rapidly intensified and struck central Luzon with an intensity of 140 kt (72 m/sec). In news reports it was cited as the most intense cyclone to strike the Philippine Islands this year. Elsie weakened dramatically as it moved across the Philippines, and did not reintensity as it traversed the South China Sea. The cyclone dissipated after making landfall in central Vietnam.

In the middle of October the Tropical Upper Tropospheric Trough (TUTT) was well established in a east-west orientation across the western North Pacific. As Typhoon Dan (29W) made landfall in central Vietnam, a tropical disturbance developed approximately 670 nm (1240 km) east-northeast of Manila and started tracking west-northwestward. The system, first

mentioned on the Significant Tropical Weather Advisory at 130600Z, was located between two small TUTT lows -- one located to the southwest and one located to the northeast of the disturbance. These TUTT lows enhanced the disturbance's upper-level outflow, and at 132330Z a Tropical Cyclone Formation Alert was issued. As the disturbance intensified, the first warning was issued on Tropical Depression 30W at 140000Z, followed by an upgrade to Tropical Storm Elsie at 141200Z. At that time, Elsie stalled as it moved into an area of weak steering flow between two subtropical highs.

Late on 15 October, Elsie began a "stair step" northwestward, as a mid-latitude short wave passed to the north. This short wave enhanced the outflow, and Elsie rapidly intensified from 60 kt (31 m/sec) to 110 kt (57 m/sec) in 24 hours. At 160600Z, Elsie was upgraded to a typhoon and became a super typhoon at 180600Z. Super Typhoon Elsie (Figure 3-30-1) reached its maximum intensity of 140 knots (72 m/sec) at 181800Z and then

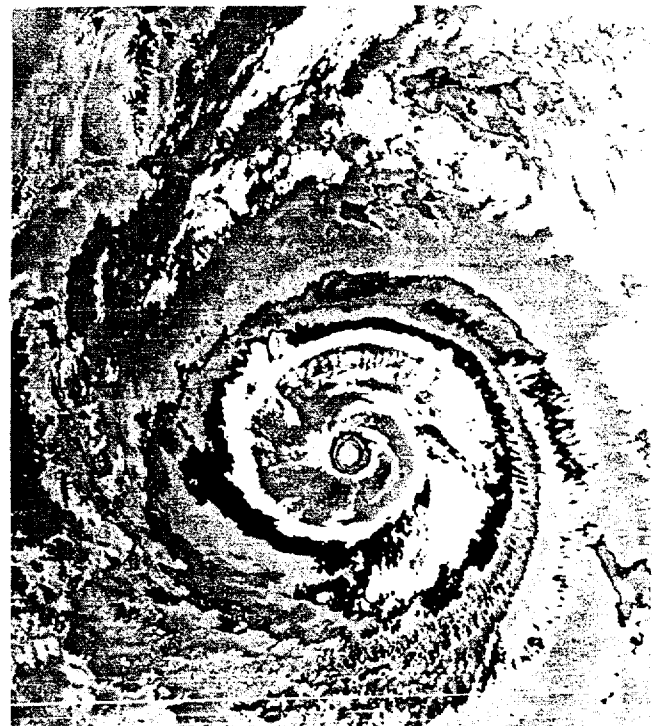
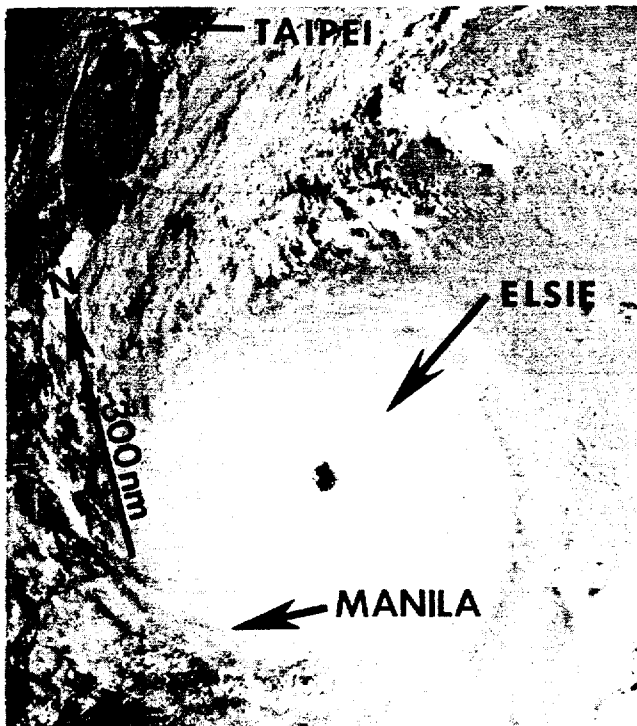


Figure 3-30-1. A matched pair of enhanced infrared (left) and visual (right) data show Elsie's classic cloud-free eye and surrounding central dense overcast (190000Z October NOAA visual and infrared imagery).

made landfall in central Luzon at 190300Z.

As it crossed Luzon, Elsie weakened rapidly due to frictional effects and the loss of oceanic sensible and latent heat sources. The system was downgraded to a typhoon at 190600Z, and then to a tropical storm at 191200Z. The tropical cyclone tracked westward along the south side of a northeast monsoonal surge. Vertical wind shear associated with the surge prevented Elsie from reintensifying in the South China Sea (Figure 3-

30-2). The final warning was issued at 220600Z as Tropical Storm Elsie made landfall in central Vietnam. The remnants remained identifiable until they reached the mountainous terrain of Laos.

In the Philippines Super Typhoon Elsie left at least 17 dead, 50,000 homeless, and damage in the millions of dollars. John Hay Air Station and Wallace Air Station sustained a total of \$30,000 damage, including damaged roofs, uprooted trees and destroyed sheds.

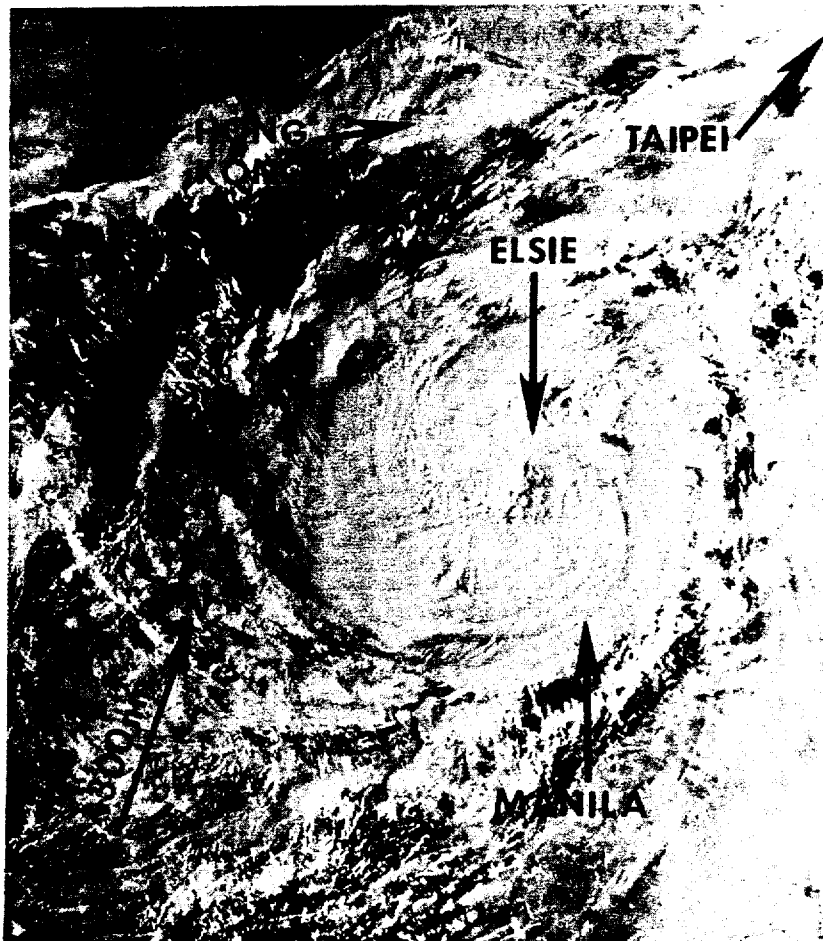
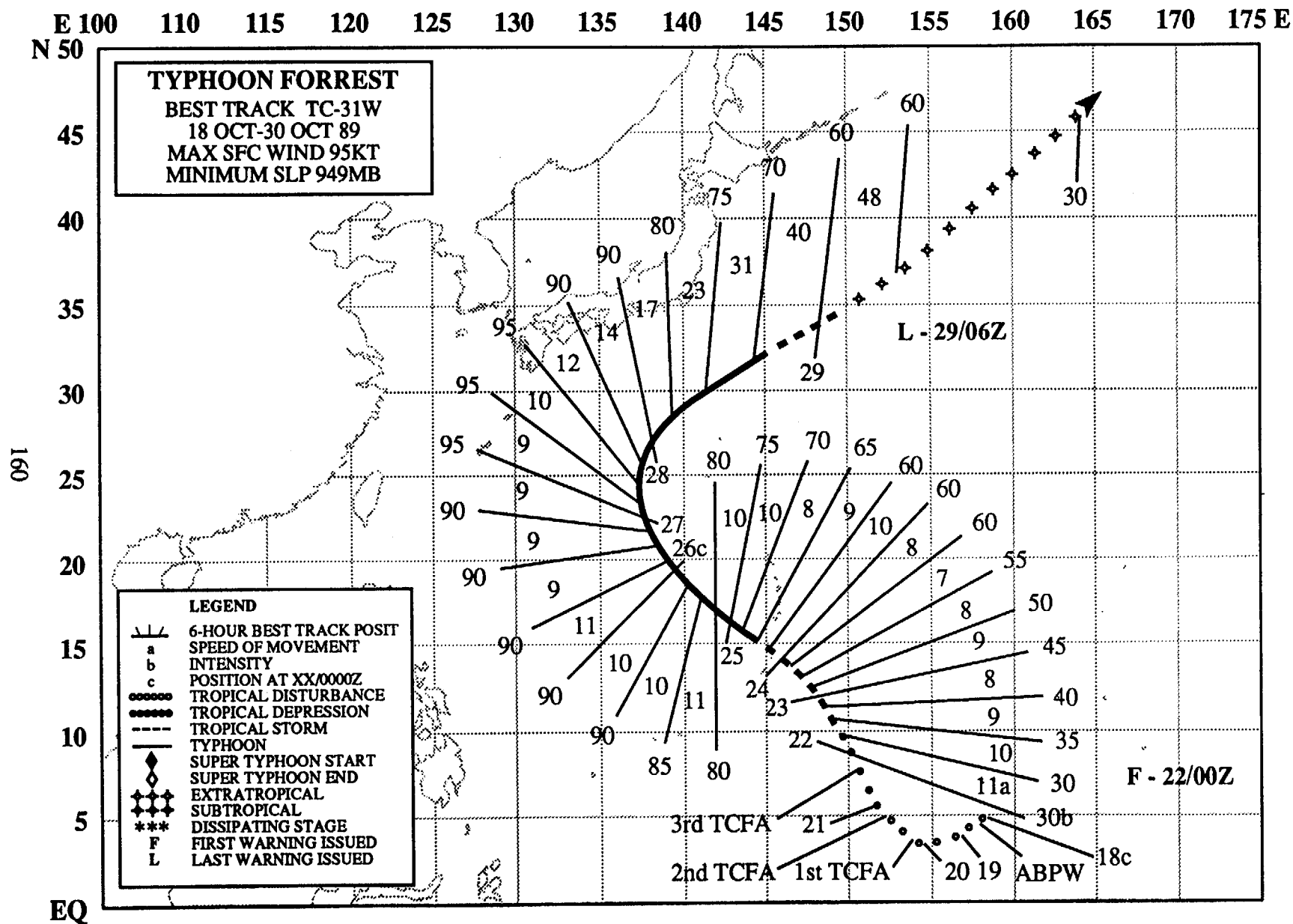


Figure 3-30-2. Elsie spins westward across the South China Sea and never regains typhoon intensity (192233Z October DMSP visual imagery).

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TYPHOON FORREST (31W)

The last of six tropical cyclones in October and the 17th typhoon of the year, Forrest was slow and erratic in its development. In fact, JTWC issued and reissued three Tropical Cyclone Formation Alerts before finally disseminating the first warning on Tropical Depression 31W. Throughout its early life, Forrest was a sloppy, broad system with large diurnal variations in its convection. After passing Guam, Forrest finally intensified and ultimately became a 95-kt (49- m/sec) typhoon. Soon thereafter, it recurved and accelerated rapidly to the northeast, becoming one of the year's strongest extra-tropical cyclones in the Pacific. Forrest's track was striking in its similarity to the track of Typhoon Colleen (28W).

As Super Typhoon Elsie (30W) approached the northern Philippines on 17 October, the near-equatorial trough reestab-

lished itself through the Marshall and eastern Caroline Islands and generated a tropical disturbance. JTWC initially discussed the disturbance located about 100 nm (185 km) south of Pohnpei on the Significant Tropical Weather Advisory on 18 October. During the next two days, the disturbance moved toward the west-southwest. Then on the morning of 20 October, it took a turn to the northwest approximately 180 nm (335 km) southeast of Truk. At 200200Z, JTWC issued the first of three Tropical Cyclone Formation Alerts, when the apparent cloud rotation on animated cloud imagery changed from anticyclonic to cyclonic, indicating the development of organized deep convection. From 20 to 22 October, the disturbance (Figure 3-31-1) underwent extremely large diurnal fluctuations in convection creating a broad circulation center and slowing intensification. The disturbance passed about 45 nm (85 km) west of Truk in the evening of 21

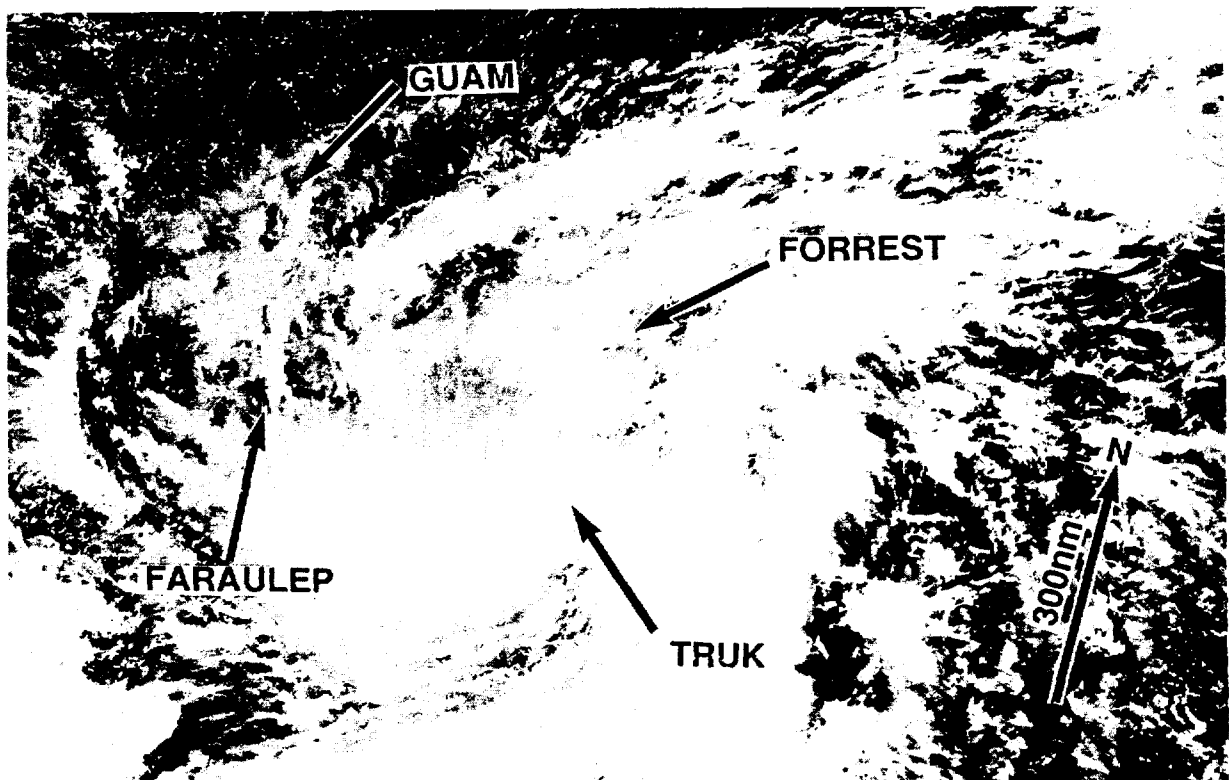


Figure 3-31-1. Forrest prior to the first warning shows a large, poorly defined circulation center (212315Z October DMSP visual imagery).

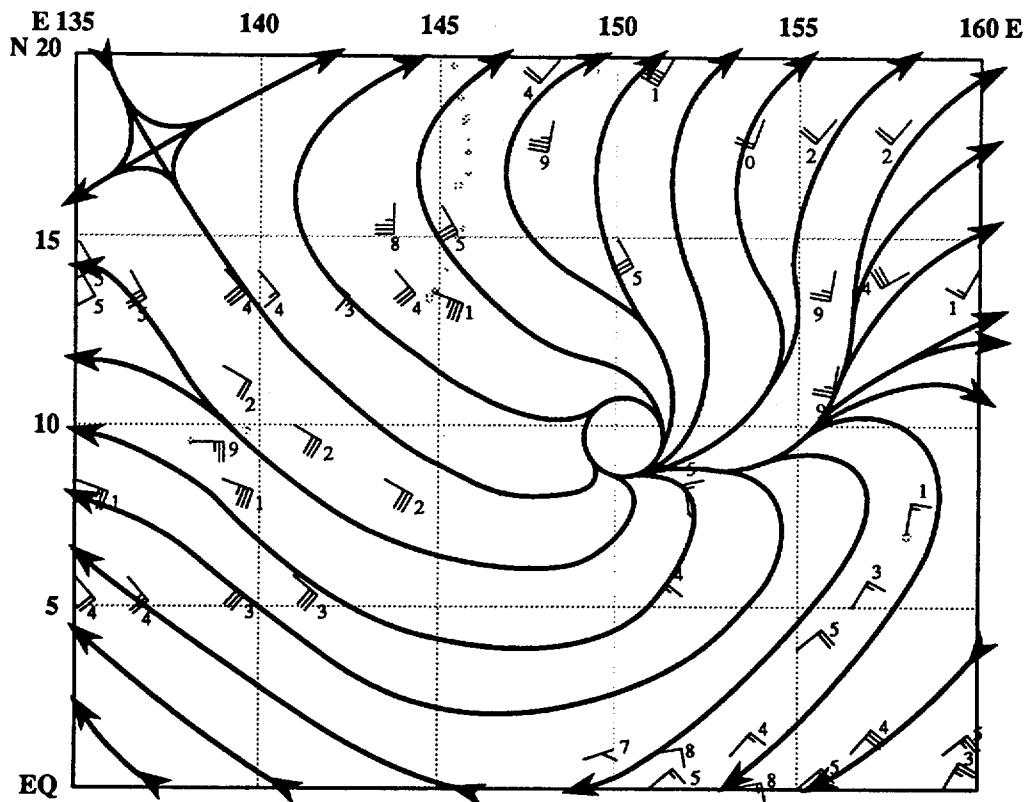
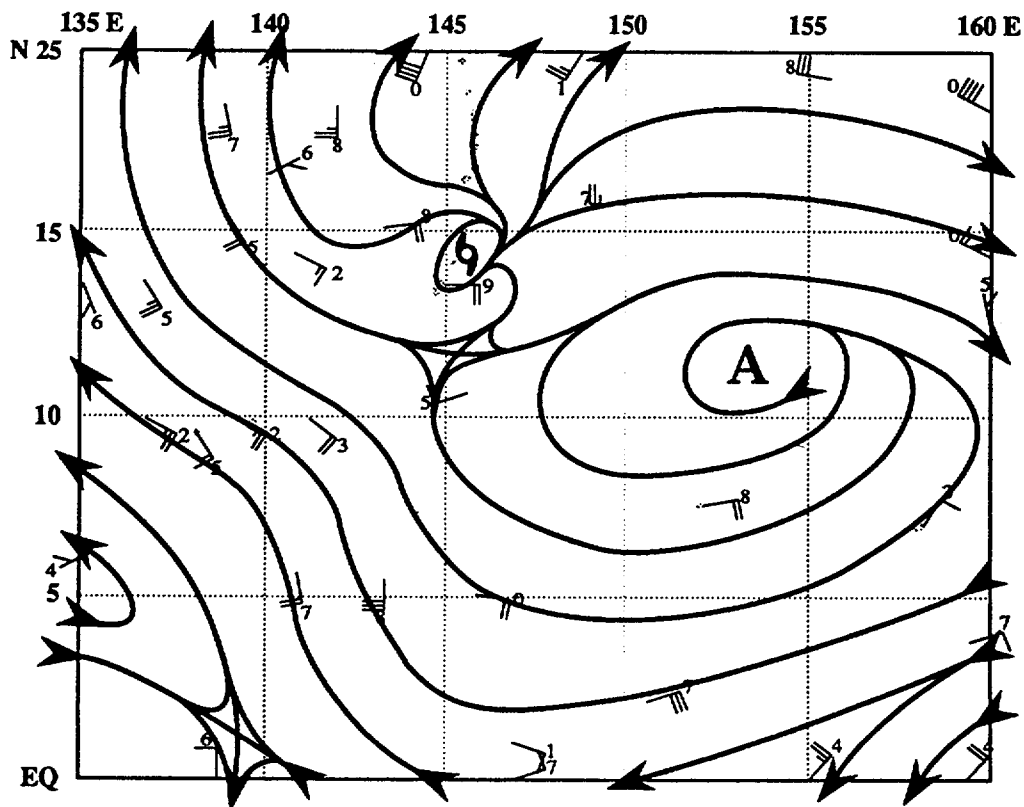


Figure 3-31-2. (a) 230000Z October 200 mb composite streamline analysis showing unrestricted outflow channels to the north and south. (b) 231200Z October 200 mb composite analysis showing the large anticyclone southeast of Forrest's main upper-level circulation center.



October. From 212100Z to 230900Z, Truk experienced sustained 20 to 25 kt (10 to 13 m/sec) surface winds from the monsoon surge associated with the disturbance. At 222000Z, the first warning was issued on Tropical Depression 31W as it reached 30 kt (15 m/sec) and developed efficient outflow channels to the north and south. Twelve hours later, the depression was upgraded to a tropical storm. Forrest moved toward the northwest and

intensified at a rate of 5 kt (3 m/sec) every 6 hours. Forecasters at JTWC expected Forrest to reach typhoon intensity as it approached Guam and to rapidly intensify 24 hours later. However, on 23 October the southern outflow channel was completely severed as a large upper-level anticyclone developed to the south of the cyclone (Figure 3-31-2) as a result of the vigorous convection in the rainband to the southeast (Figure 3-31-3). This, coupled with

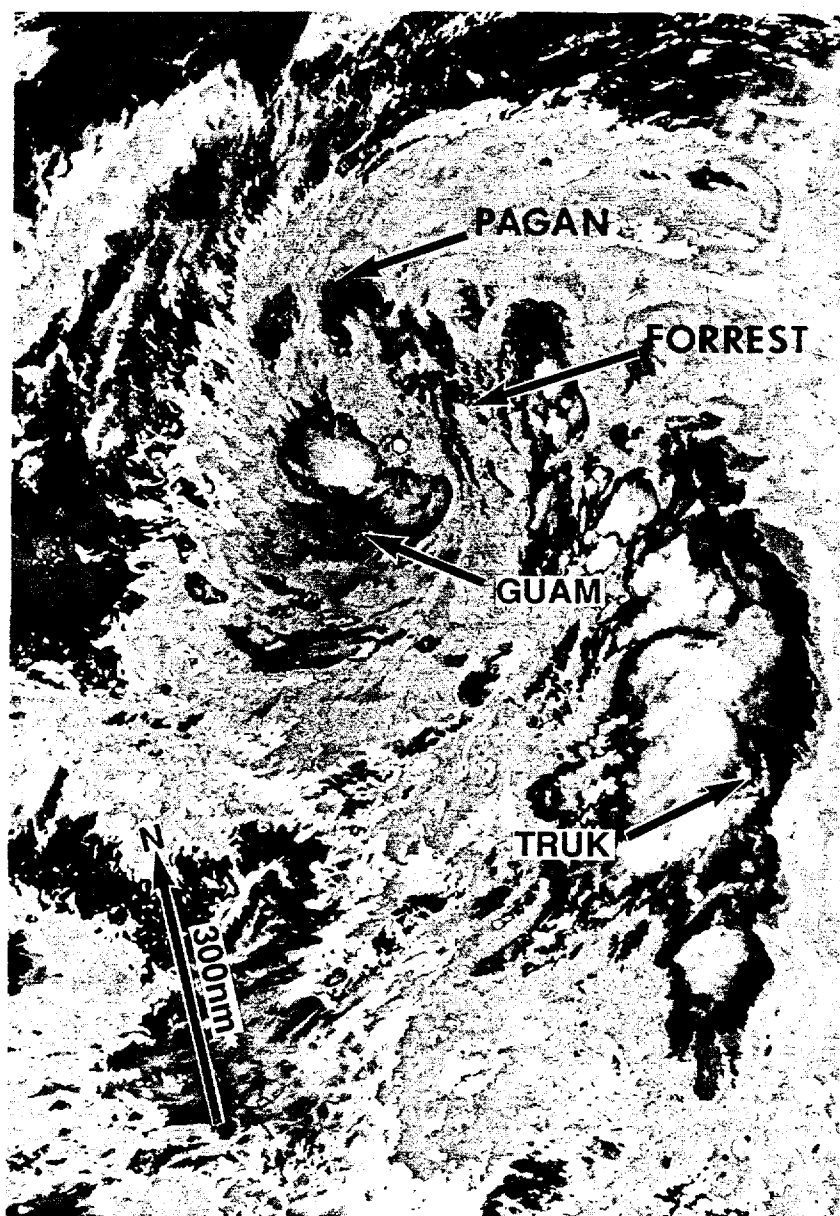


Figure 3-31-3. As Forrest nears Guam, a wide ribbon of deep convection to the southeast of the center contrasts with small area of central convection (232207Z October NOAA visual imagery).

the normal tendency for suppressed daytime convection, resulted in a convectively inactive, broad circulation center. Without the organized convection, winds remained relatively strong aloft, but weak at the surface, especially over land. At 240800Z, Forrest passed within 75 nm (140 km) of the International Airfield on Guam. The weather station (WMO 91212) recorded gusts to 34 kt (18 m/sec) and a minimum sea level pressure of 998 mb. Strong vertical wind

shear the following day did ground aircraft on Guam and Saipan. During the day, convection remained disorganized, but about 8 hours after passing Guam, convection rapidly increased and Forrest, which was close to Saipan, intensified and formed a banding type eye. Even though the typhoon was moving away from Saipan, it buffeted the island with moderately strong winds, downing tree limbs and power lines. The airport at Saipan (WMO 91232) recorded a

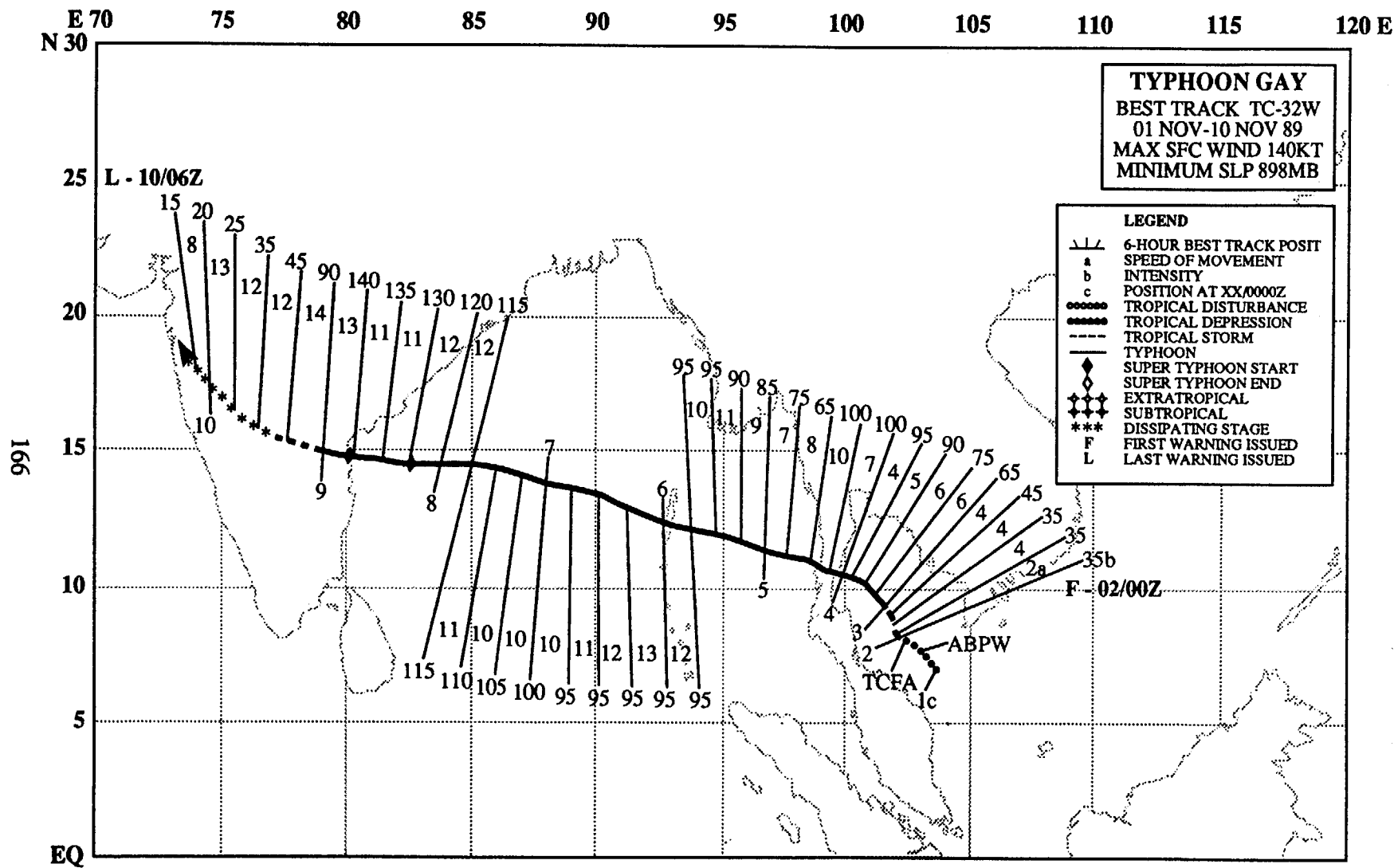


Figure 3-31-4. Enhanced infrared image of Typhoon Forrest at peak intensity (271632Z October NOAA infrared imagery).

minimum pressure of 991 mb at 250400Z, several hours after Forrest had passed. Capitol Hill at an elevation of 1000 ft (305 m) above sea level unofficially recorded wind gusts to 50 kt (26 m/sec). Reports stated that Forrest left most of the island without power, stopped air travel, closed schools, and flooded low-lying areas.

The typhoon continued its north-westward track at an average speed of 10 kt (19 km/hr). Twelve hours prior to recurvature, Forrest attained its peak intensity of 95 kt (49 m/sec) as it crossed the axis of the mid-tropospheric sub-tropical ridge (Figure 3-31-4). Following recurvature at 271200Z, the cyclone began to accelerate to the northeast. On the evening of 26 October, a typhoon acceleration prediction technique (Weir, 1982) used to help determine the timing of recurvature and acceleration indicated that Forrest was about to recurve, and that it would rapidly accelerate. In response, JTWC altered its forecast considerably to reflect the anticipated changes. This caused the USS Carl Vinson battle group to alter its course from one passing across the storm's expected track to one that kept it

northwest of that track off the coast of Japan. While recurvature and acceleration were delayed 12 to 18 hours making the speed of JTWC's forecast too fast, the direction forecast was correct. Remaining over relatively warm water and maintaining an efficient outflow channel into the mid-latitude westerlies, Forrest did not rapidly weaken. At 281200Z, the typhoon had accelerated to nearly 30 kt (56 km/hr), and still packed 75-kt (39-m/sec) winds, partly as a result of its rapid motion along track. At this time, Forrest passed within 175 nm (325 km) to the northwest of Chichijima (WMO 47971) where 850 mb winds were recorded at 230 degrees at 65 kt (33 m/sec). Interacting with the mid-latitude westerlies, Forrest's convective heat engine finally gave way to baroclinic energy-producing processes and the storm became extratropical while moving northeastward at nearly 50 kt (93 km/hr). The final warning on Typhoon Forrest was issued at 290600Z. Like Colleen, the resulting extratropical system became one of the strongest winter storms in the Pacific during 1989, packing storm force winds in excess of 60 kt (31 m/sec).



TYPHOON GAY (32W)

The first tropical cyclone of November turned out to be the worst tropical cyclone to affect the Malay Peninsula in 35 years. Gay developed in the Gulf of Thailand, crossed the Malay Peninsula into the Bay of Bengal and slammed into India with peak sustained winds of 140 kt (70 m/sec). Unique because of its small size, intensity, and point of origin, Gay challenged forecasters by crossing two different tropical cyclone basins and almost entering a third.

From a climatological point of view, an occasional tropical cyclone may move into the Gulf of Thailand from the South China Sea, but it is rare for genesis and intensification to occur in the Gulf — a relatively small body of water surrounded by land on three sides. However, on the first of November, satellite imagery detected the presence of a concentrated area of convection with a well-organized upper-level anticyclone. At the same time, sparse ship reports in the Gulf showed that sea-level pressures were relatively high — near 1008 mb. The continued increase in the amount and organization of convection prompted JTWC to mention it on the 010600Z Significant Tropical Weather Advisory, noting that a low-level circulation was evident in the monsoon trough. Maximum sustained surface winds were estimated to be 10 to 15 kt (5 to 8 m/sec). During the next 15 hours, the disturbance continued to consolidate and estimated winds increased to 25 kt (13 m/sec). At 012100Z, JTWC issued a Tropical Cyclone Formation Alert.

Aided by its small size, dual outflow channels to the north and south, and the warm Gulf waters, the tropical cyclone spun up rapidly, and at 020000Z JTWC issued a 36-hour Tropical Depression Warning on Tropical Depression 32W. It became apparent that the cyclone would continue intensification, and six hours later, JTWC issued the first 72-hour Tropical Cyclone Warning on the system, upgrading it to tropical storm intensity. As Gay intensified, it presented a paradox to forecasters. While the satellite intensity estimates correctly diagnosed intensification, the synoptic data in Malaysia and Thailand indicated weakening winds and higher pressures. The synoptic data were correctly interpreted as indicators of increased subsidence produced by the intensifying midlevel system. Subsequent JTWC warnings thus reflected that Gay would reach typhoon intensity.

At 021800Z, Gay began to intensify more rapidly than anticipated reaching typhoon intensity at 030000Z. The eye apparently passed directly over the *Seacrest*, a commercial oil drilling ship moored in the Gulf. Confused seas with estimated heights of 35 to 45 feet (11 to 14 m) caused the ship to capsize shortly after eye passage. Gay's intensification continued, reaching 100 kt (51 m/s) at 040600Z just before it crashed into Champhun, Thailand which is located 210 nm (390 km) south-southwest of Bangkok. The radar at Champhun (WMO 48517) had tracked Gay for 18 hours, before its reports abruptly ceased shortly before the

typhoon (Figure 3-32-1) came inshore. At least four hundred and fifty-eight people were died and over 600 fishermen were reported missing at sea. In addition, two hundred fishing vessels were lost or missing.

As Gay moved slowly to the northwest in the Gulf, JTWC forecasters anticipated that a ridge would build to the north, and correctly forecast the cyclone to make a left turn and move across the Malay Peninsula. Gay weakened briefly as it crossed the Peninsula, entering the Bay of Bengal with maximum winds of 65 kt (33 m/s) at 041200Z. Situated south of the mid-level ridge, Gay continued to track west-northwestward across the Bay of Bengal at an average speed of 10 kt (19 km/hr).

Gay intensified slowly in an area of weak vertical wind shear and warm sea surface temperatures, reaching an intensity of 95 kt (49 m/sec) by 051200Z. Restrictions to the upper-level outflow inhibited further development for the next 36 hours.

At 070000Z, Gay attained an intensity of 100 kt (51 m/sec), and took a more westward course as the mid-level ridge strengthened to the north. Without any significant restrictions to its outflow, the cyclone intensified for the next 42 hours until it reached the coast of India. Gay (Figure 3-32-2) reached super typhoon intensity at 080600Z, with winds of 130 kt (67 m/sec). Gay (Figure 3-32-3) made landfall in a sparsely populated area of India approximately 120 nm

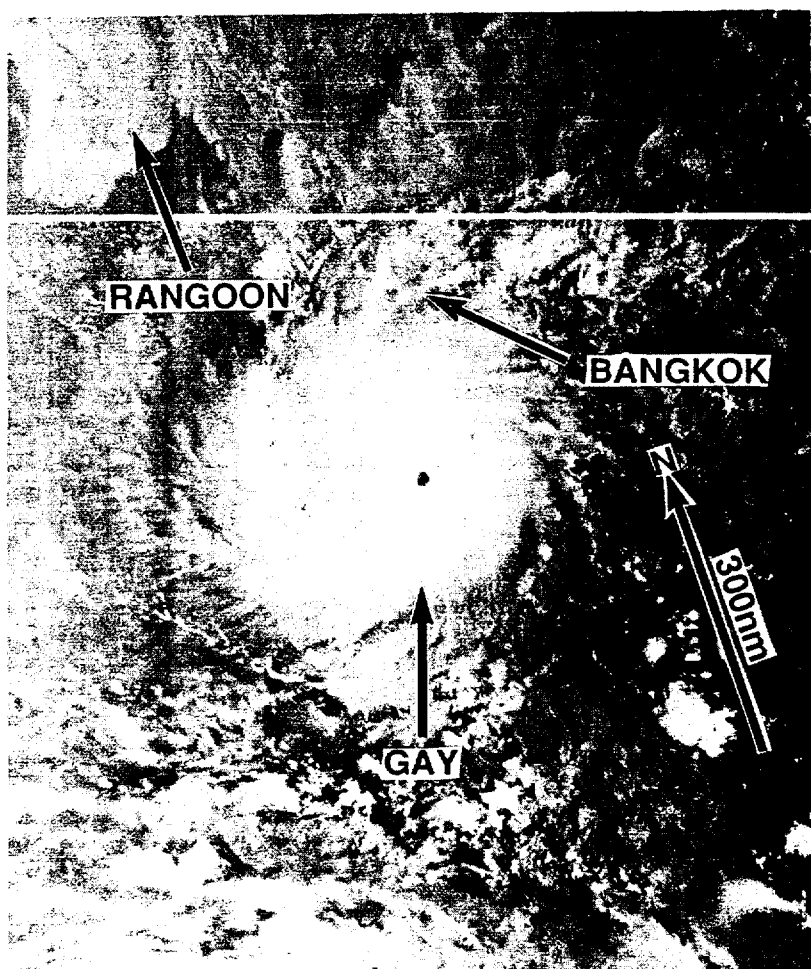


Figure 3-32-1. Typhoon Gay as it makes landfall on the Malay Peninsula. More than 1000 people were reported dead or missing in Gay's aftermath (040042Z November NOAA visual imagery).

(220 km) north of Madras at 081800Z, with maximum sustained winds estimated at 140 kt (72 m/sec). While there was concern that the Dvorak intensity estimation technique might have overestimated Gay's intensity, photos of destruction showed that Gay was a very intense, but very small, cyclone. In-country analyses of Indian synoptic data indicated that the 30-kt (15-m/sec) wind radii did not extend much beyond 50 nm (95 km) — (personal communication with Dr. G. S. Mandal, Indian Meteorological Service).

Twelve hours after making landfall, Gay had weakened to 45 kt (23 m/s). Because of the possibility of its reemergence into the

Arabian Sea, JTWC continued to issue warnings on the system as it moved across India at 13 kt (24 km/hr). After 090600Z, Gay took a more northwestward overland track. At 100600Z, JTWC issued its final warning as the system dissipated in the Western Ghats approximately 75 nm (140 km) southeast of Bombay. Gay weakened much faster than anticipated as it moved across India. This was a result of its small size and small over-water fetch. Once inland the small fetch, which supplied Gay's latent heat source, was rapidly cut off. Because Gay was so small and went inshore in a rural area, it caused only 39 deaths. However, over 20,000 homes were destroyed or damaged.

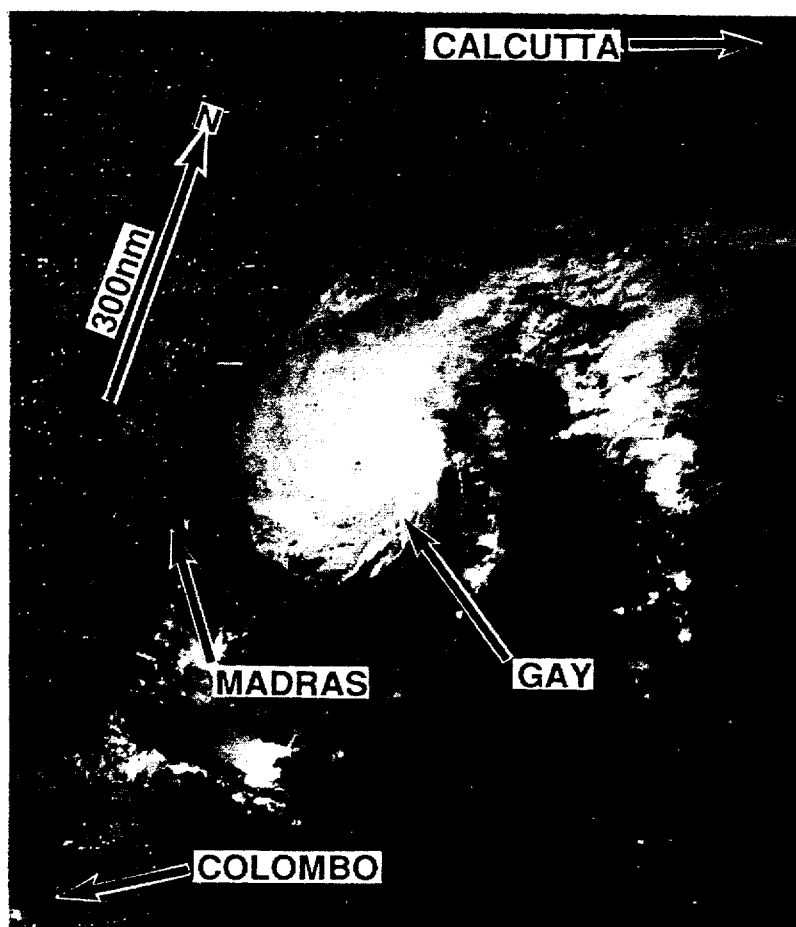


Figure 3-32-2. Gay approaches super typhoon intensity. The small eye appears in a small, compact central dense overcast (080340Z November DMSP visual imagery).

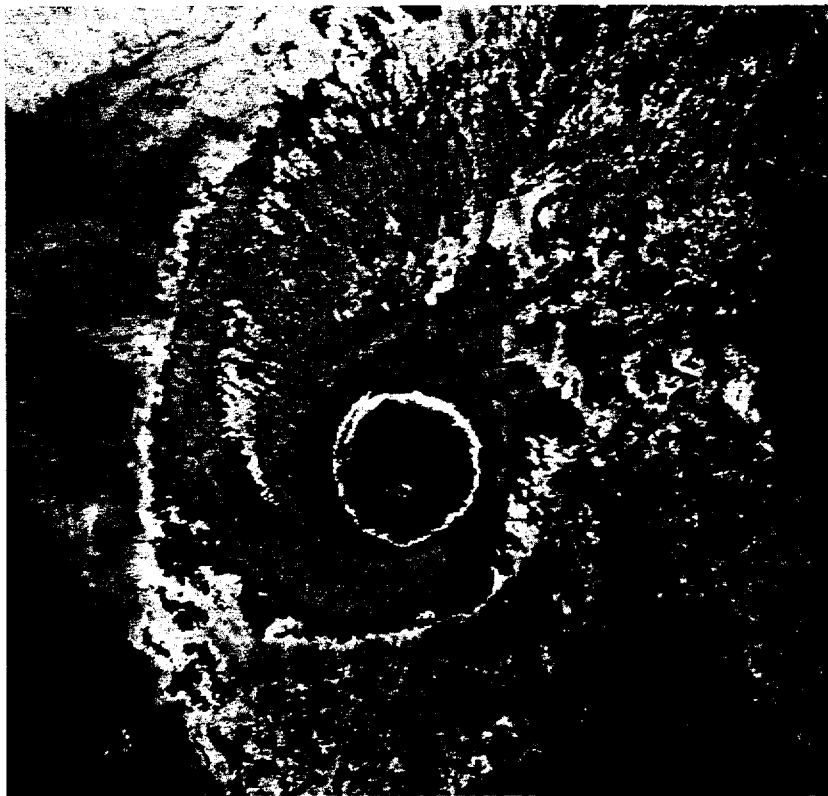
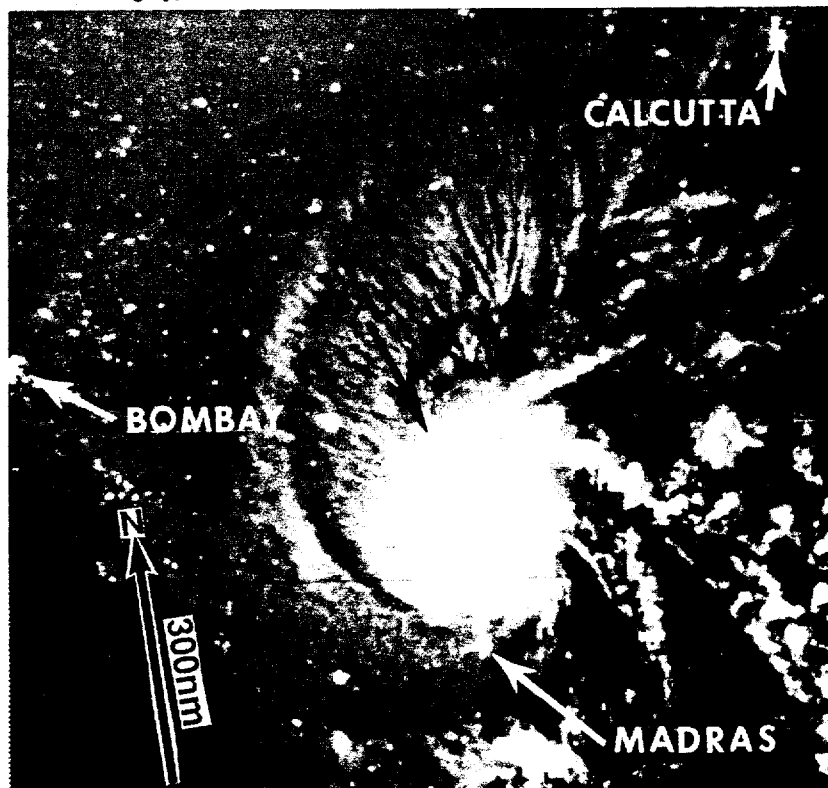


Figure 3-32-3. Enhanced infrared (above) and low-light visual (below) satellite picture pair of Gay at the coast of India. The city lights, the moonlit coast line and Gay's cloudiness show on the visual image. The enhanced infrared reveals the small eye and cold surrounding overcast (081612Z November DMSP visual and infrared imagery).



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TYPHOON HUNT

BEST TRACK TC-33W
10 NOV-24 NOV 89
MAX SFC WIND 90KT
MINIMUM SLP 954MB

LEGEND

-  6-HOUR BEST TRACK POSIT
-  a SPEED OF MOVEMENT
-  b INTENSITY
-  c POSITION AT XX/0000Z
-  TROPICAL DISTURBANCE
-  TROPICAL DEPRESSION
-  TROPICAL STORM
-  TYPHOON
-  SUPER TYPHOON START
-  SUPER TYPHOON END
-  EXTRATROPICAL
-  SUBTROPICAL
-  DISSIPATING STAGE
-  FIRST WARNING ISSUED
-  LAST WARNING ISSUED

35

30

25

20

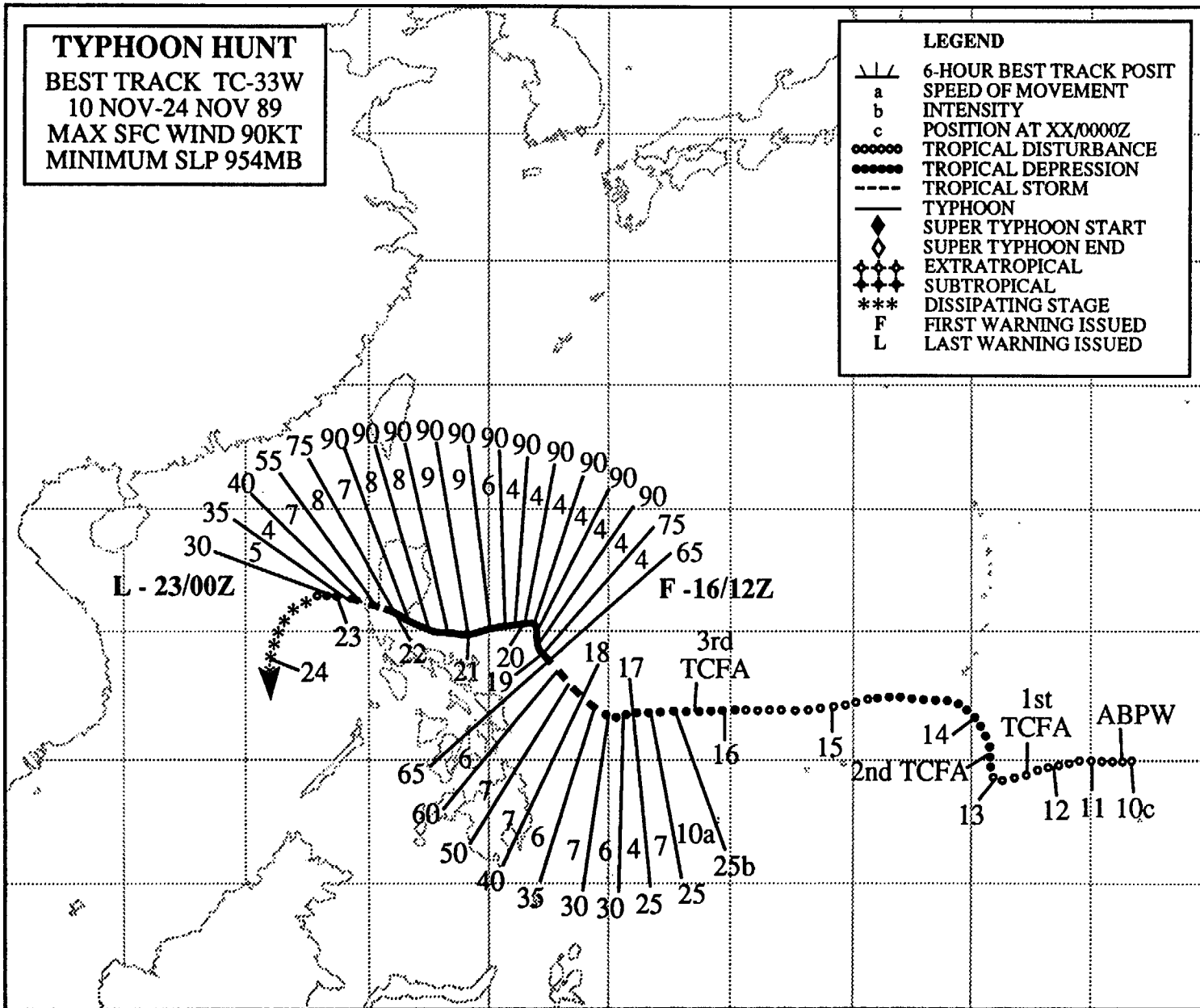
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TYPHOON HUNT (33W)

Typhoon Hunt was the fourth typhoon, following Angela (26W), Dan (29W) and Elsie (30W), to strike the Philippine Islands within six weeks. Generally a westward moving system, it was slow to develop, but finally intensified rapidly in the western Philippine Sea. As it intensified and approached the Philippines, it underwent a northwestward "stair step" before resuming a westward course into central Luzon. Unlike Angela (26W), Dan (29W) and Elsie (30W) which reintensified after crossing Luzon, Hunt weakened dramatically and dissipated in the South China Sea.

Except for Typhoon Gay (32W), early November was relatively inactive in the western North Pacific. The cloud cluster that became Typhoon Hunt was first identified on the 10 November Significant Tropical Weather Advisory. This system was a weak tropical disturbance embedded in the monsoon trough north of the island of Truk in the central Caroline Islands. The cloud cluster remained poorly defined and drifted slowly westward for two days. After synoptic data indicated falling surface pressures, JTWC issued a Tropical Cyclone Formation Alert at 121000Z. The disturbance was located 270 nm (500 km) southeast of Guam. As the passage of a mid-latitude trough to the northeast of Guam weakened the mid-level subtropical ridge. On 13 November, the disturbance executed an abrupt track change to the north towards Guam. The Alert was reissued at 131000Z, approximately 220 nm (405 km) south-southeast of Guam.

The system moved northward for a day, then turned sharply westward, passing 90 nm (165 km) south of Guam. Increasing vertical shear weakened the convection significantly, and the Alert was canceled at 140400Z. On 16 November, the organization of the disturbance improved, as southwesterly winds of 20 to 30 kt (10 to 15 m/sec) were reported by ships and land stations. JTWC issued its third Alert on

the system at 160730Z.

Continued organization led to the first warning on Tropical Depression 33W at 161200Z. In response to a mid-latitude trough passage to the north, the depression appeared to slow and then dip southward for six hours. As the trough moved out to the northeast, the 500 mb ridge remained very narrow but split into two cells, one to the northwest of the tropical cyclone and another to the northeast. A broad col area remained north of the tropical depression which then moved northwestward towards this weakness.

At 180000Z, the depression was upgraded to Tropical Storm Hunt with maximum sustained winds of 35 kt (18 m/sec). Hunt intensified rapidly while moving northwestward and was upgraded to a typhoon at 181800Z. JTWC continued to forecast movement over Luzon and predict the system would enter the South China Sea just south of Manila Bay. This was based on NOGAPS prognostic fields which indicated that the narrow 500 mb ridge would reestablish and maintain itself to the north of the system, thus forcing a westward track. At the same time, a strong 850 mb ridge of continental polar air associated with the winter monsoon extended eastward from southern China. This was also expected to block Hunt's northward progression. However, the NOGAPS forecast series proved to be too fast at reestablishing the ridge and Hunt turned northward toward the weakness in the ridge.

At this time, the typhoon also slowed to 4 kt (7 km/hr). Now JTWC and U.S. forces from the Philippines to Okinawa faced the dilemma of having a destructive system either affect forces in the Philippines should Hunt make only a "stair step," or in Okinawa, should it recurve. Because weak mid-latitude troughs, embedded in the predominantly zonal flow, continued to pass north of the tropical cyclone, and the prognostic series continued to build the

narrow 500 mb ridge as a barrier to Hunt's continued northward movement, JTWC persisted with its forecast of westward movement.

At 091500Z Typhoon Hunt, with its 90-kt (46-m/sec) maximum sustained winds, turned sharply to the west toward central Luzon as the 500 mb ridge to the system's northeast built westward and strengthened. Hunt remarkably maintained its 90-kt (46-m/sec) intensity for 66 continuous hours before moving ashore in central Luzon at 212000Z (Figure 3-33-1). Army personnel involved in the joint-combined U.S.-Philippine exercise, BALIKATAN 89, were deployed to Fort Magsaysay near Clark AB. The Weather Support Force for the exercise reported peak winds of 52 kt (27 m/sec) at 212200Z when Hunt was 40 nm (75

km) northeast of its location. As the typhoon crossed Luzon, it killed at least seven Filipino people. Damage to military installations was slight.

Hunt was downgraded to a tropical storm at 220600Z as it entered the Lingayen Gulf. The northeast monsoon was of moderate strength in the South China Sea, and Hunt, despite moving over warm water, continued to weaken due to strong vertical wind shear. Deep convection had completely subsided by 230000Z when Hunt was downgraded to a tropical depression and the final warning was issued. The remains of the low-level circulation, although not visible on satellite imagery, were last discernible on synoptic charts at 240000Z drifting southward in the monsoonal flow.

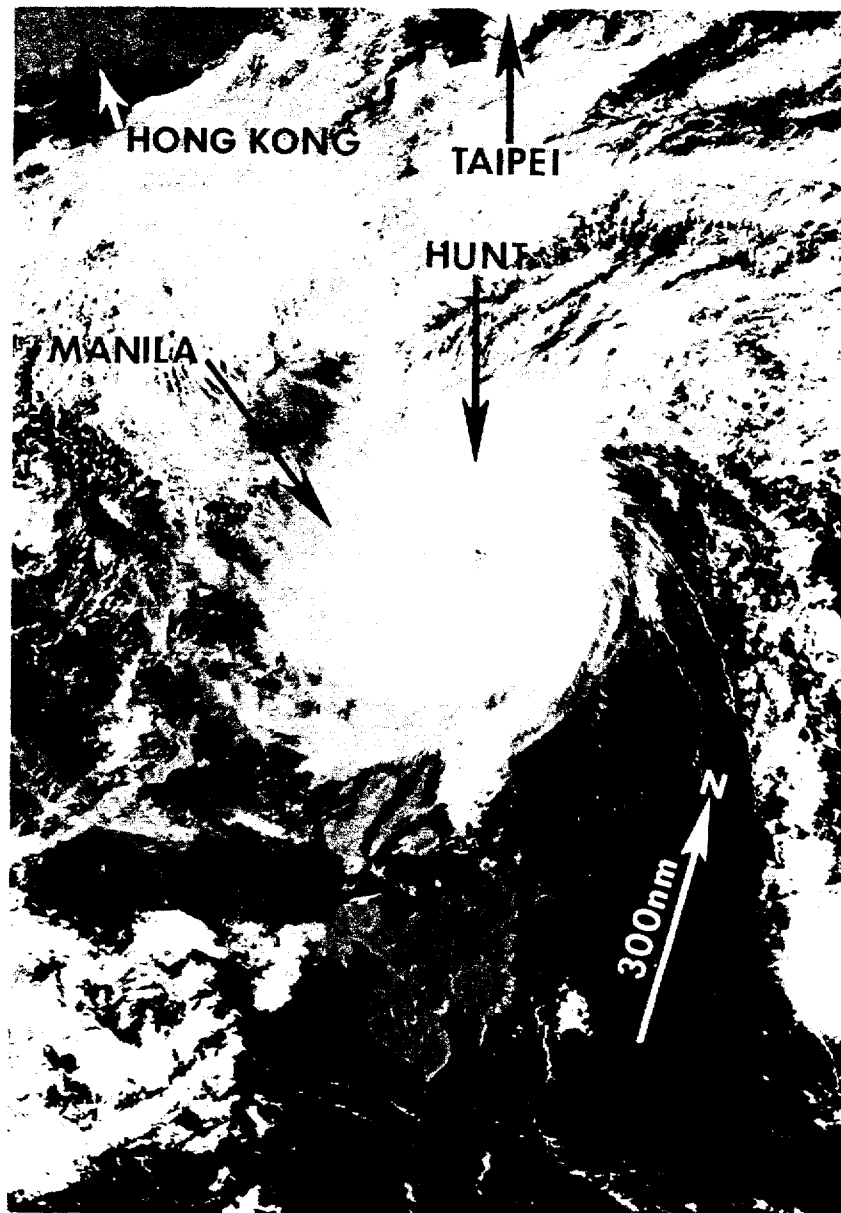
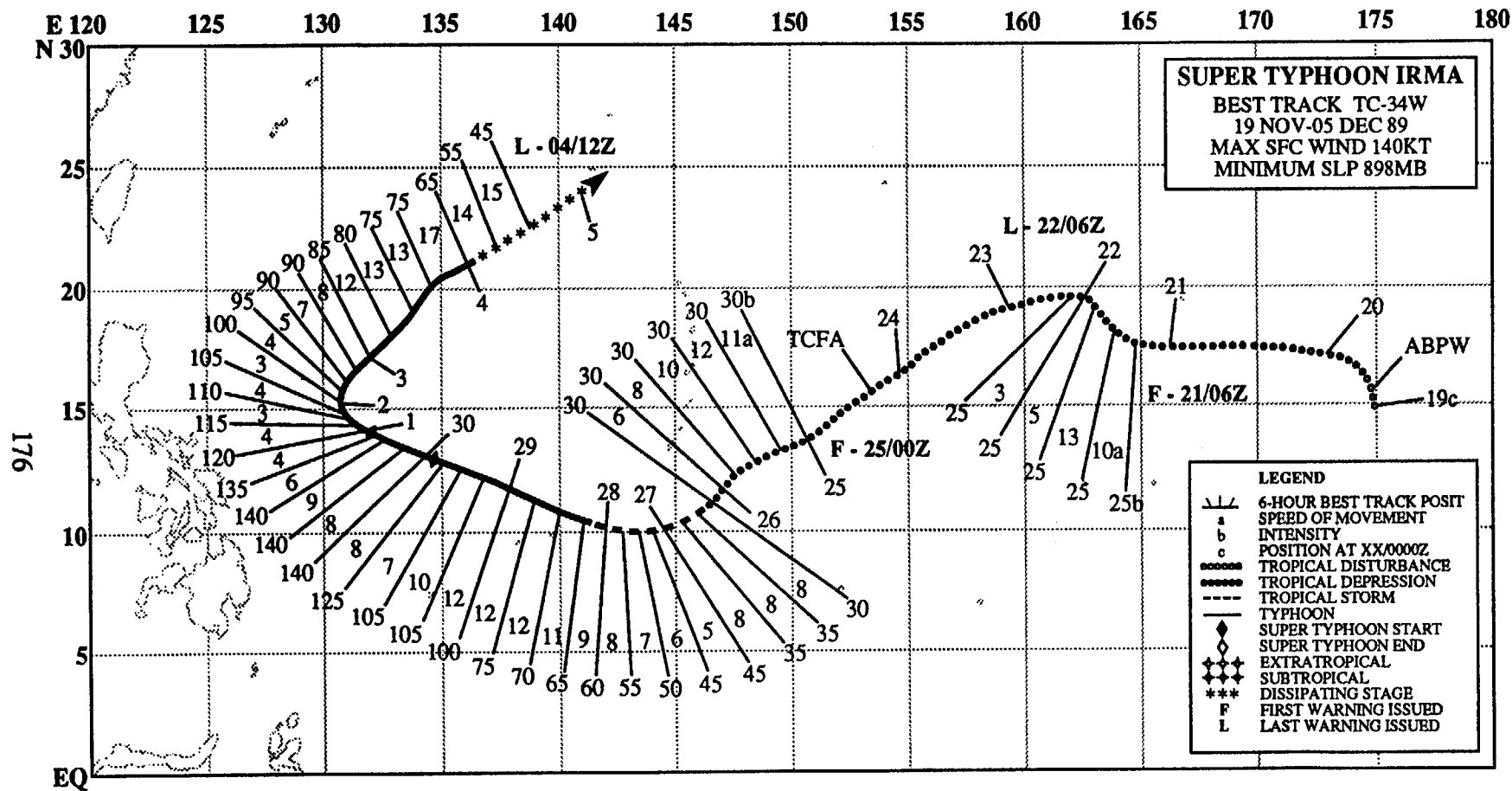


Figure 3-33-1. Typhoon Hunt approximately nine hours before landfall on central Luzon. Maximum sustained winds are estimated at 90 kt (46 m/sec) (211130Z November DMSP visual imagery).



SUPER TYPHOON IRMA (34W)

Irma was the third and final tropical cyclone to form in November. Its development and track were dictated by complex mid-latitude and monsoonal regimes. Initially, Irma was slow to develop, however, rapid intensification followed once it was in the Philippine Sea. Irma lasted 17 days and required a total of 39 warnings -- only Super Typhoon Angela (26W) exceeded this longevity with a total of 46 warnings.

In the middle of November, disturbed weather associated with a TUTT low developed 580 nm (1075 km) northeast of Kwajalein Atoll in the Marshall Islands. The disturbance was first mentioned on the Significant Tropical Weather Advisory at 182300Z. Because of significant vertical wind shear affecting the system, JTWC opted for a 36-hour Tropical

Depression Warning at 210600Z instead of a 72-hour Tropical Cyclone Warning. Increasing upper-level flow around the TUTT low led to increasing shear above the depression, and a final Tropical Depression Warning followed at 220600Z. However, JTWC continued to mention the poorly defined remnants each day on the Significant Tropical Weather Advisory.

From 22 to 27 November, the system moved a record-breaking five days to the southwest, traveling from 20° to 10° north latitude. During this period from 22 to 24 November, the system tracked southwestward along the edge of a shear zone and continued to exhibit partially tropical characteristics. Eventually the southwestward track carried the system into an area of less vertical wind shear, where a flare up in convective activity led to a

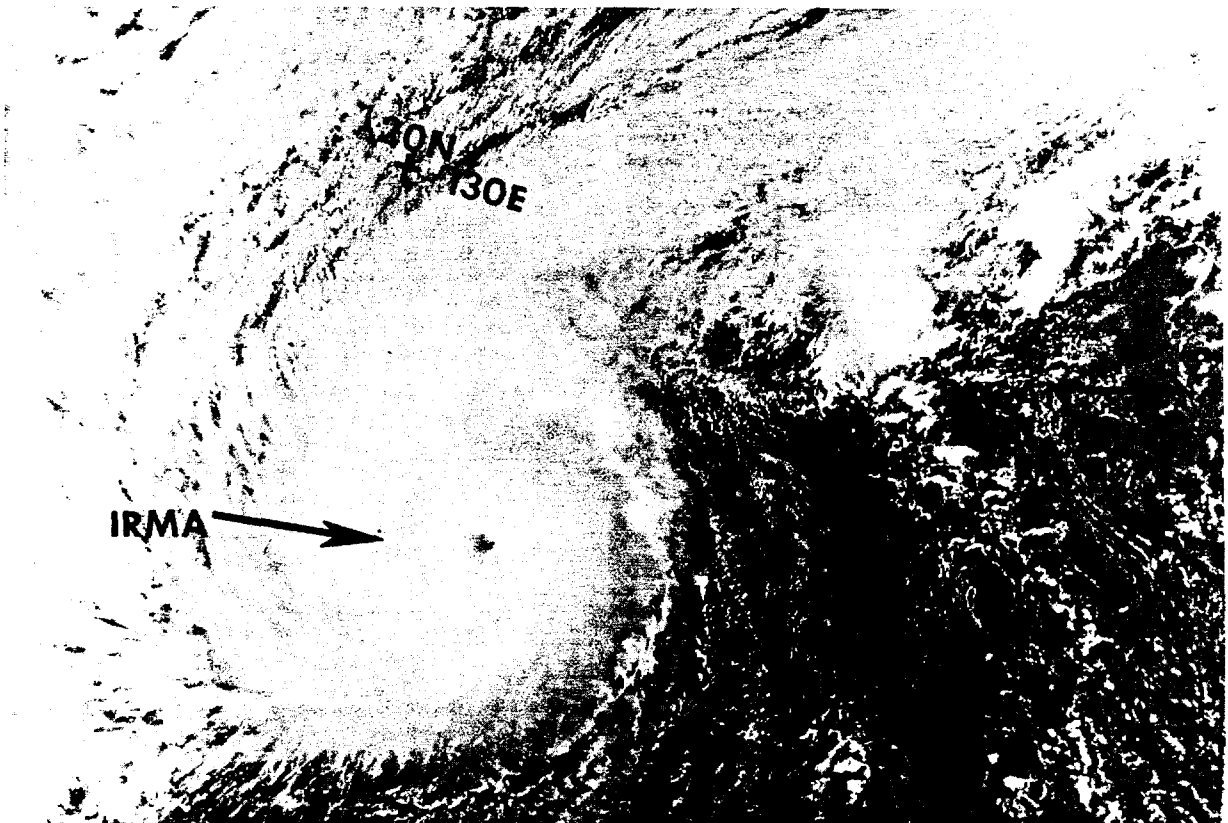


Figure 3-34-1. An extensive field of closed cell stratocumulus appear to the north through west of Super Typhoon Irma (300431Z November NOAA visual imagery).

Tropical Cyclone Formation Alert at 240600Z. This development continued and at 250000Z a Tropical Depression Warning was issued. As the polar air mass along the shear line became well-modified in the tropics and anticyclonic outflow became more symmetric aloft, conditions improved for development. At 261200Z, JTWC issued the first Tropical Cyclone Warning on Tropical Depression 34W.

As the track became more westerly at 261800Z, Tropical Depression 34W was upgraded to Tropical Storm Irma. As a mid-latitude short wave trough approached from the northwest, enhancing Irma's outflow, rapid intensification occurred and JTWC upgraded

the tropical cyclone to a typhoon at 280600Z. As a second short wave approached, Irma (Figure 3-34-1) attained super typhoon intensity at 300000Z. This increase in intensity was short lived, however. With the passage to the east of the shortwave also came stronger westerly winds aloft and an accompanying surge in the low-level northeast monsoon. These factors, plus the entrainment of cold air, weakened Irma (Figure 3-34-2) below super typhoon intensity at 010000Z.

Since 27 November the track to the west-northwest brought Irma closer to the polar westerlies aloft. Irma's forward motion slowed gradually as the cyclone approached the western

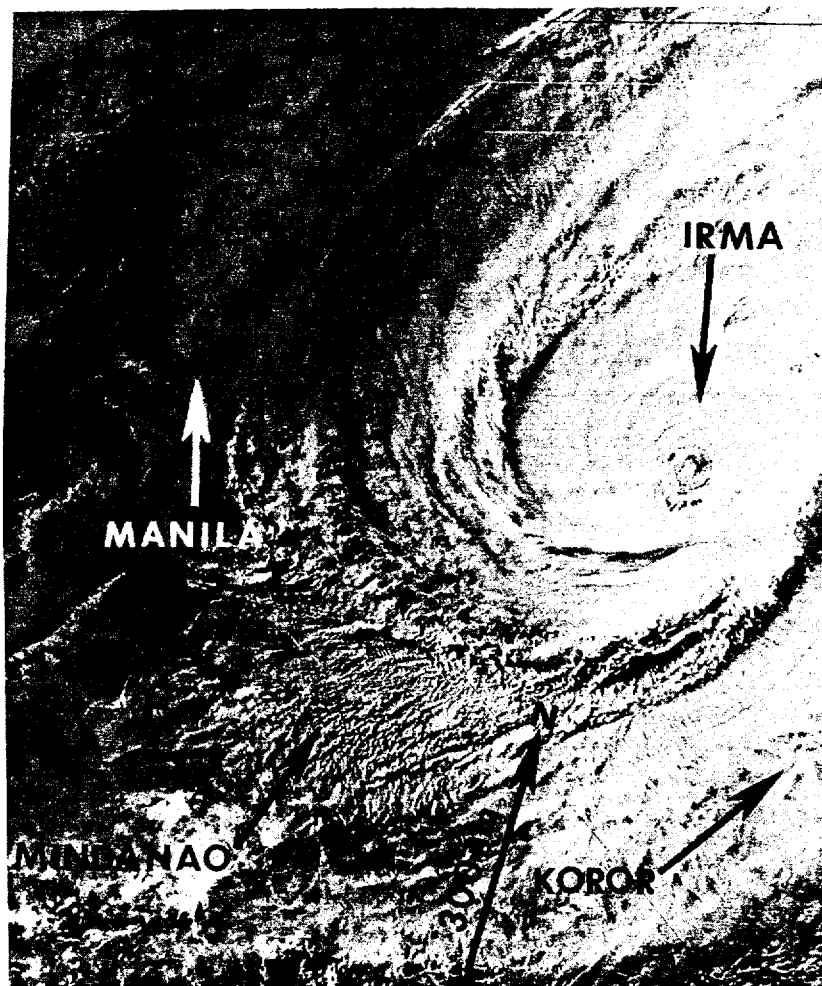
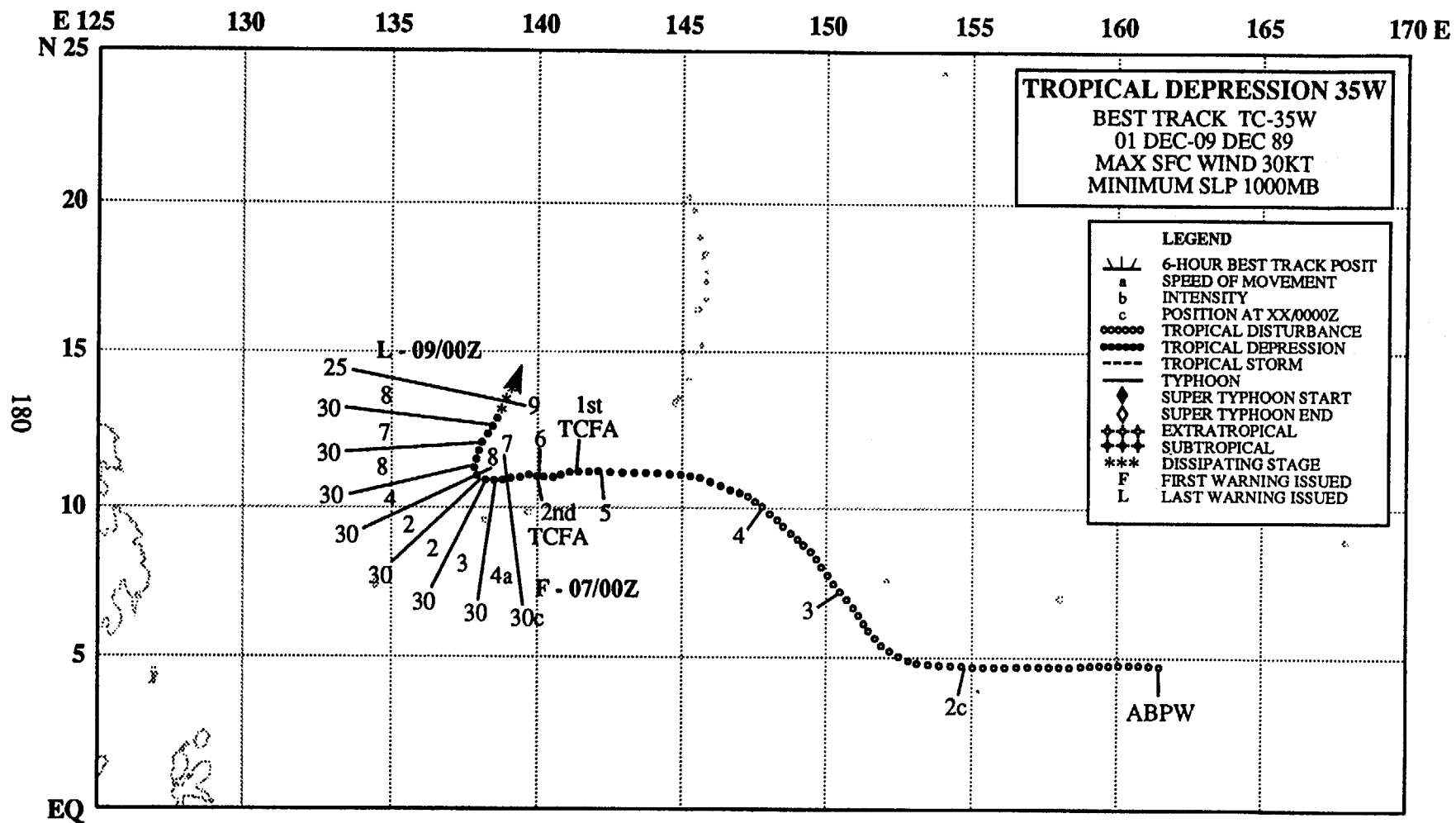


Figure 3-34-2. Irma's central dense overcast is elongated and asymmetrical. The eye is filling with clouds and the super typhoon is weakening (302151Z November DMSP visual imagery).

periphery of the subtropical ridge. The entire fall of 1989 had be characterized by zonal westerly mid-tropospheric flow and a very narrow subtropical ridge in the extreme western Pacific. Because of the 250 nm (465 km) wide ridge, even straight moving cyclones were very close to becoming recurvature ones. JTWC expected the flow to remain zonal, and for Irma to resume westward movement into the Philippine Islands. However, on 2 December, another short wave moved eastward from the

coast of Asia. This trough deepening further equatorward than the previous short waves and Irma recurved 630 nm (1165 km) east of Manila. The typhoon accelerated in response to the stronger westerly flow aloft and weakened in the strong shearing environment. The final warning was issued at 041200Z. The remnants of Irma were no longer visible on the satellite imagery on 5 December. JTWC received no reports of damage caused by Irma.



TROPICAL DEPRESSION 35W

Detected on the first day of December, Tropical Depression 35W lasted more than a week as a discrete system, although it was in warning status only 48 hours.

As Super Typhoon Irma (34W) was weakening in the Philippine Sea, a weak surface circulation and an associated area of convection were detected in the western Marshall Islands. The tropical disturbance was mentioned on the 010600Z Significant Tropical Weather Advisory as a poor suspect area. Over the next five days this tropical disturbance moved generally west-northwestward and continued to organize very slowly. The presence of strong vertical wind shear arrested development and eventually

weakened the system. After the disturbance passed to the south of Guam, the convection flared and at 050500Z the first Tropical Cyclone Formation Alert was issued. The Alert was reissued at 060500Z. Then, based on a satellite intensity estimate of 30-kt (15-m/sec) surface winds (Figure 3-35-1), a Tropical Cyclone Warning was issued at 070000Z. At 080000Z, the approach of a mid-level short wave trough from the northwest resulted in the depression abruptly changing track and recurving northeastward. Increased vertical wind shear from the west-southwest was responsible for further weakening the system. The final warning was issued at 090000Z as the cyclone dissipated over water.

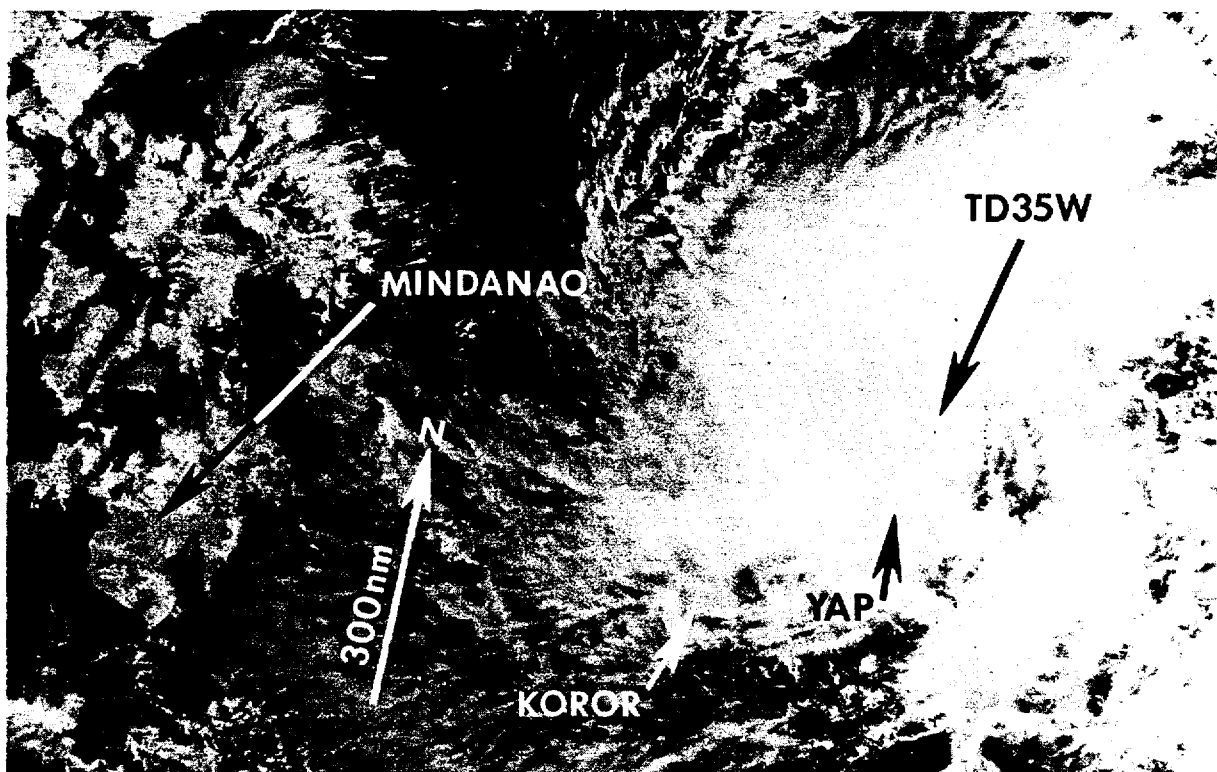
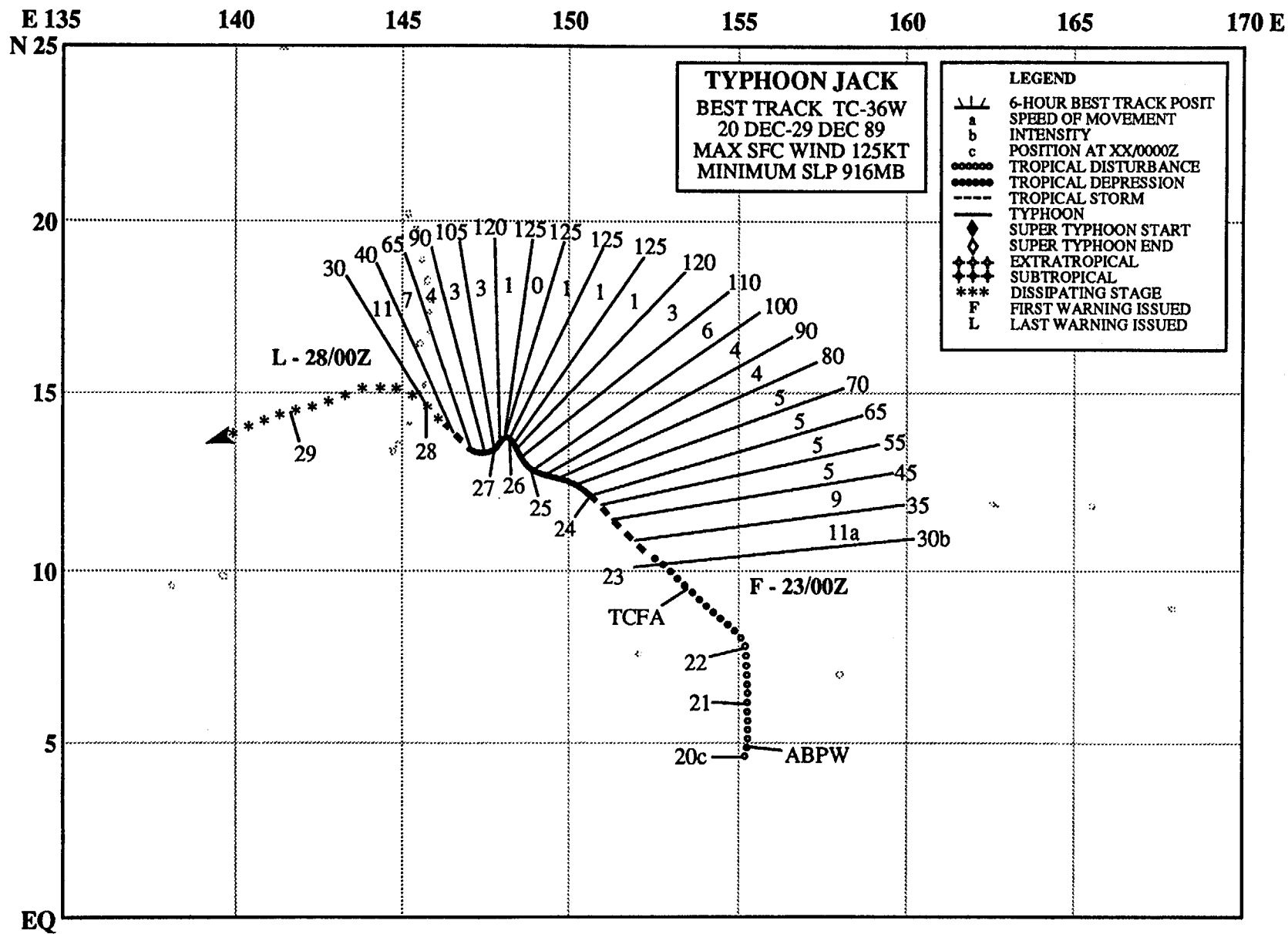


Figure 3-35-1. Tropical Depression 35W with 30-kt (15-m/sec) maximum sustained surface winds (070457Z December NOAA visual imagery).



TYPHOON JACK (36W)

The second tropical cyclone to form in December, Jack was the twenty-first typhoon and final tropical cyclone of the year. Typhoon Jack was noteworthy for the unusually long period it remained quasi-stationary and the extremely rapid dissipation that followed.

A broad area of poorly organized convection located approximately 240 nm (445 km) southeast of Truk was first noted on the 210600Z Significant Tropical Weather Advisory. The disturbed area of weather continued to organize slowly and a Tropical Cyclone Formation Alert was issued at 221900Z. At that time, the disturbance was 150 nm (275 km) northeast of Truk, moving west-northwestward at 8 kt (15 km/hr) with surface winds of 20 to 30 kt (10 to 15 m/sec). Over the next 8 hours, the upper-level anticyclonic circulation and the spiral bands of the disturbance increased significantly in organization, however, the low-level circulation

remained weak. The combination of the rather tentative intensification of the disturbance and its movement in the general direction of Guam prompted the issuance of a Tropical Depression Warning at 230000Z. At that time Tropical Depression 36W was approximately 400 nm (740 km) southeast of Guam and forecast to move northwestward at 11 kt (20 km/hr).

The low-level organization of Tropical Depression 36W appeared to improve markedly on satellite imagery resulting in the issuance of a Tropical Cyclone Warning at 230600Z. The motion forecast for the next four days called for continued northwestward movement toward a weakness in the subtropical ridge near Guam, followed by recurvature due to an approaching short-wave trough. The system did reach a weak area at the axis of the subtropical ridge in about two days. However, the broad nature of the ridge blocked Jack's movement in all directions. This caused the cyclone to stall in a

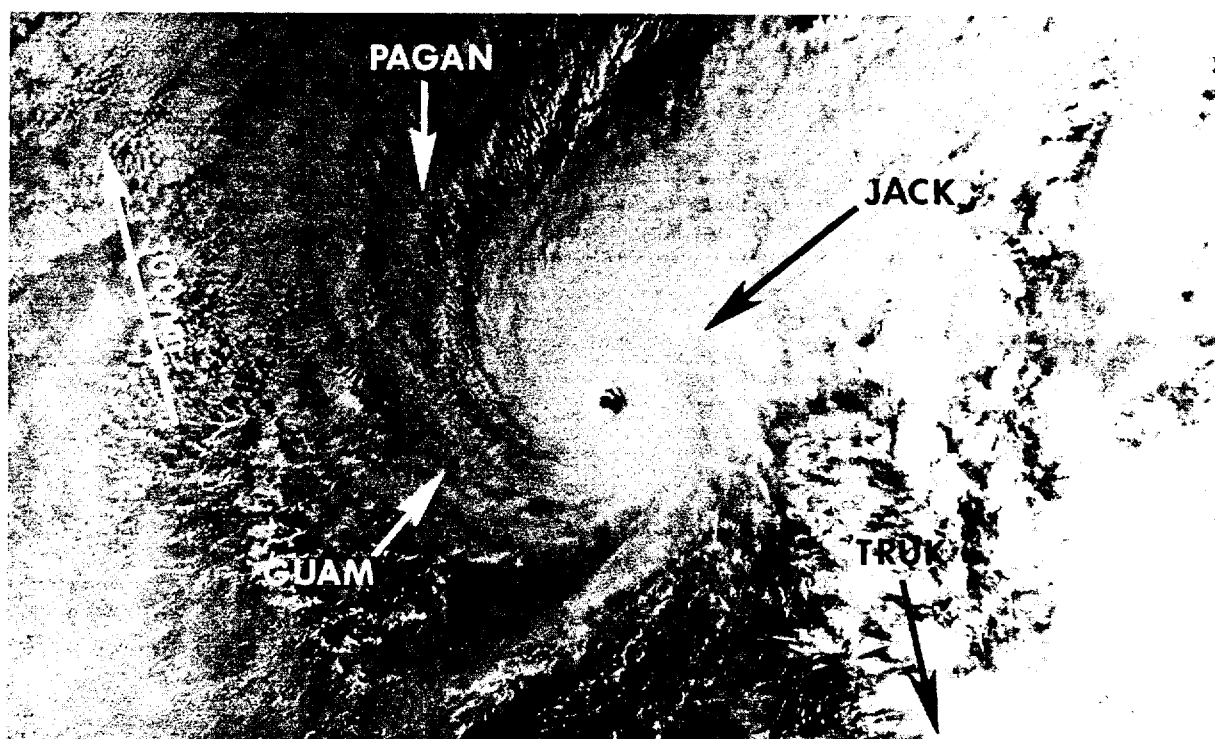


Figure 3-36-1. Jack near super typhoon intensity (252148Z December NOAA visual imagery).

large area of weak mid-level steering at a latitude too far south to permit the passing short-wave trough to initiate recur-vature. Jack had closed to within 185 nm (345 km) of Guam before stalling. The proximity to Guam allowed surveillance to be conducted by the weather radar at Andersen AFB (WMO 91218). In what is almost certainly a record for almost no motion, radar surveillance documented that Jack moved only about 60 nm (110 km) from 250710Z to 270335Z, and moved less than 20 nm (35 km) from 251210Z to 261210Z. Jack's eye, with a diameter of 20 to 30 nm (37 km to 55 km), made an ideal target for remote sensing. The typhoon was essentially stationary in a non-shearing environment for nearly 48 hours.

Not surprisingly, the unusual motion of Typhoon Jack was accompanied by an equally unusual intensification and dissipation pattern. From a maximum wind speed of 30 kt (15

m/sec) at 222330Z, Jack rapidly deepened to a maximum wind speed of 115 kt (57 m/sec) at 250530Z, which corresponds to nearly two T-numbers per day using the Dvorak intensity estimation technique. It reached a peak intensity of 125 kt (67 m/sec; Dvorak T6.5) during the period 251800Z to 261200Z (Figure 3-36-1). Such an intensification pattern was unusual since Jack appeared to have only one well-defined outflow channel to the northeast. Normally, rapid deepening and the attainment of super-typhoon intensity are associated with the development of two efficient outflow channels.

As Jack began to show signs of prolonged quasi-stationary behavior, JTWC anticipated on the 260000Z warning that the upwelling of cold water at the cyclone's center, normally associated with the wind stress on the ocean's surface, might initiate a rapid weakening of the system due to its slow movement. Although

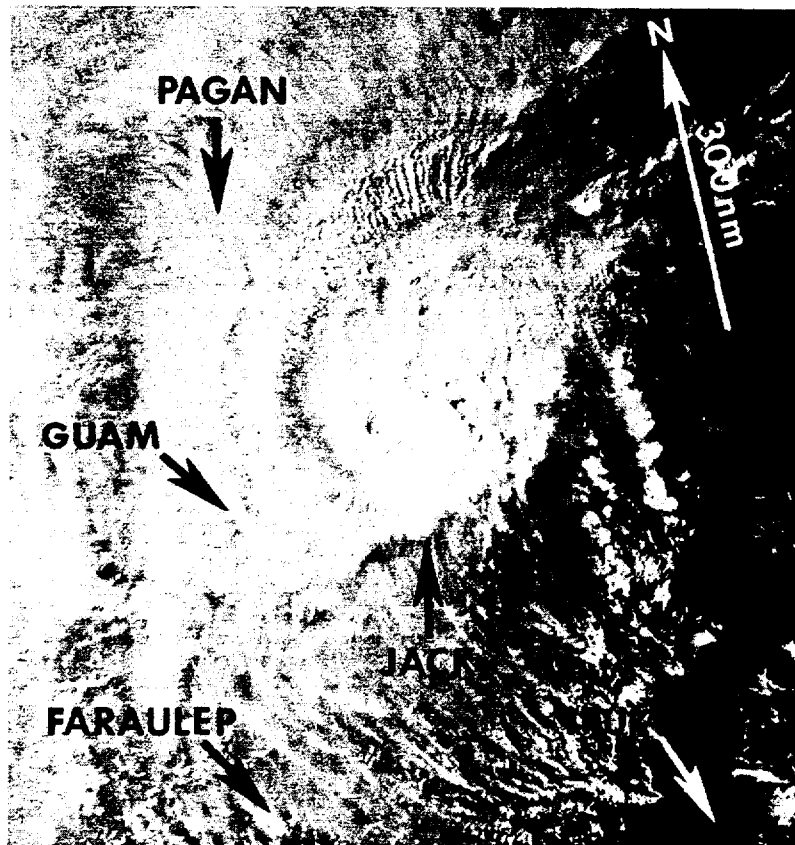


Figure 3-36-2. Jack as an intense typhoon only 24 hours before dissipation (262126Z December NOAA visual imagery).

such weakening did indeed occur, the extreme nature of the ensuing dissipation was surprising. At 270000Z, JTWC assessed the intensity of Jack (Figure 3-36-2) to be about 105 kt (54 m/sec). Figure 3-36-3 shows the remnants of Jack 24 hours later. All that remained was a 30-kt (15-m/sec) exposed low-level circulation center located 120 nm (220 km) northeast of Guam. This remarkable weakening rate exceeded 15 kt (8 m/sec) per 6 hour forecast period. The

remnants of the associated convective cloud mass were about 300 nm (555 km) to the south of the low-level circulation center. The vorticity associated with the cloud mass actually developed a secondary low-level circulation center that moved south of Guam on 28 December. Of interest, NOAA imagery on 29 December detected a cold water cyclonic eddy in the ocean where Jack had been quasi-stationary for nearly two days.

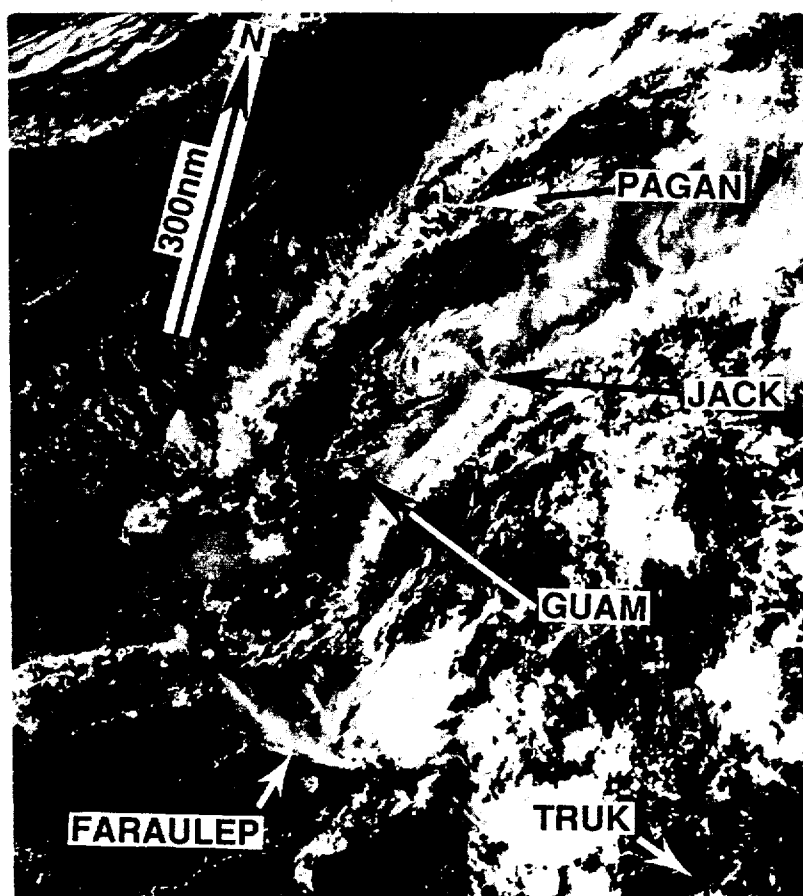


Figure 3-36-3. The remnants of Jack: an exposed low-level circulation center northeast of Guam, and the last vestige of the convection cloud mass to the south (272357Z December DMSP visual imagery).

3.3 NORTH INDIAN OCEAN TROPICAL CYCLONES

Spring and fall in the North Indian Ocean are periods of transition between major climatic controls and the most favorable seasons for tropical cyclone activity (Tables 3-5 and 3-6). Two significant tropical cyclones developed in the North Indian Ocean in the spring, however, no tropical cyclones developed in the fall transition season. The most interesting

event was the passage of Tropical Cyclone 32W (Gay) into the Bay of Bengal from the Gulf of Thailand. It maintained typhoon intensity while crossing the Malay Peninsula and reached super typhoon intensity which is rare in the Bay of Bengal.

In summary, 1989 tropical cyclone activity was below the 1988 and 15-year average of five (Table 3-6).

TABLE 3-5. 1989 SIGNIFICANT TROPICAL CYCLONES
NORTH INDIAN OCEAN

TROPICAL CYCLONE	PERIOD OF WARNING	NUMBER OF WARNINGS ISSUED	MAXIMUM SURFACE WINDS-KT (M/SEC)	ESTIMATED MSLP (MB)
TC 01B	23 MAY - 26 MAY	14	55 (28)	984
TC 02A	12 JUN - 13 JUN	5	35 (18)	996*
TC 32W	04 NOV - 10 NOV	25	140 (72)	898
TOTAL:		44		

* BASED ON SYNOPTIC DATA

TABLE 3-6. NORTH INDIAN OCEAN
TROPICAL CYCLONES DISTRIBUTION

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1971*	-	-	-	-	-	0	0	0	0	1	1	0	2
1972*	0	0	0	1	0	0	0	0	2	0	1	0	4
1973*	0	0	0	0	0	0	0	0	0	1	2	1	4
1974*	0	0	0	0	0	0	0	0	0	0	1	0	1
1975	1	0	0	0	2	0	0	0	0	1	2	0	6
1976	0	0	0	1	0	1	0	0	1	1	0	1	5
1977	0	0	0	0	1	1	0	0	0	1	2	0	5
1978	0	0	0	0	1	0	0	0	0	1	2	0	4
1979	0	0	0	0	1	1	0	0	2	1	2	0	7
1980	0	0	0	0	0	0	0	0	0	0	1	1	2
1981	0	0	0	0	0	0	0	0	0	1	1	1	3
1982	0	0	0	0	1	1	0	0	0	2	1	0	5
1983	0	0	0	0	0	0	0	1	0	1	1	0	3
1984	0	0	0	0	1	0	0	0	0	1	2	0	4
1985	0	0	0	0	2	0	0	0	0	2	1	1	6
1986	1	0	0	0	0	0	0	0	0	0	2	0	3
1987	0	1	0	0	0	2	0	0	0	1	2	2	8
1988	0	0	0	0	0	1	0	0	0	1	2	1	5
1989**	0	0	0	0	1	1	0	0	0	0	1	0	3

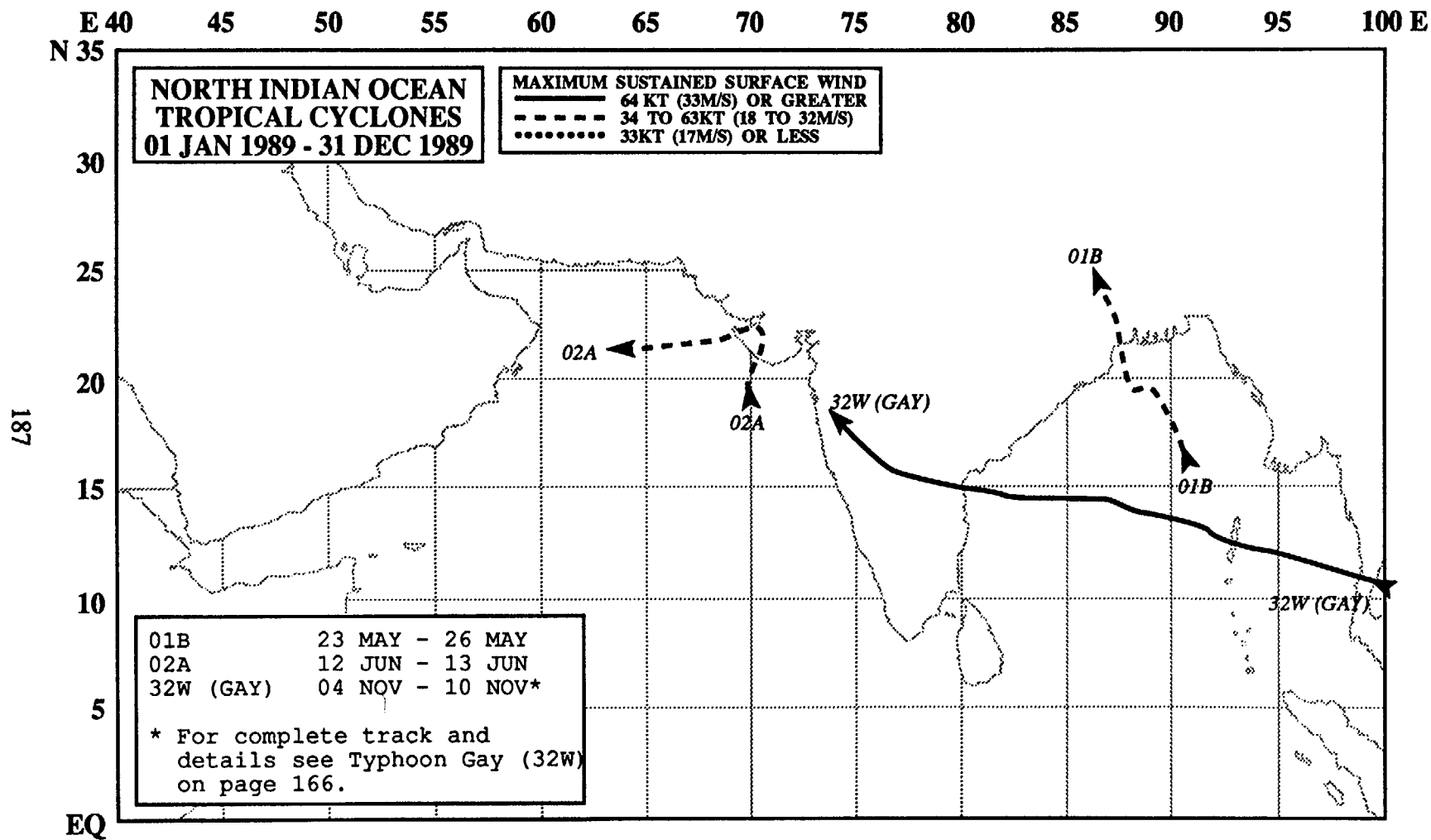
(1975-1989)

AVERAGE:	0.1	0.1	0.0	0.1	0.7	0.5	0.0	0.1	0.2	1.0	1.5	0.5	4.6
TOTAL:	2	1	0	1	10	8	0	1	3	14	22	7	69

* JTWC WARNING RESPONSIBILITY BEGAN ON 4 JUNE 1971 FOR THE BAY OF BENGAL, EAST OF 90° EAST LONGITUDE. AS DIRECTED BY CINCPAC, JTWC ISSUED WARNINGS ONLY FOR THOSE TROPICAL CYCLONES THAT DEVELOPED OR TRACKED THROUGH THAT PART OF THE BAY OF BENGAL. COMMENCING WITH THE 1975 TROPICAL CYCLONE SEASON, JTWC'S AREA OF RESPONSIBILITY WAS EXTENDED WESTWARD TO INCLUDE THE WESTERN PART OF THE BAY OF BENGAL AND THE ENTIRE ARABIAN SEA.

** JTWC ISSUED EIGHT TROPICAL CYCLONE FORMATION ALERTS. FORMATION ALERTS WERE ISSUED FOR ALL OF THE SIGNIFICANT TROPICAL CYCLONES THAT DEVELOPED IN 1989. TROPICAL CYCLONE 32W WAS IN WARNING STATUS WHEN IT ENTERED THE BAY OF BENGAL.

WARNINGS: NUMBER OF CALENDAR WARNING DAYS: 13
THERE WERE NO CALENDAR WARNING DAYS WITH TWO OR MORE TROPICAL CYCLONES.



E 75 80 85 90 95 100 E

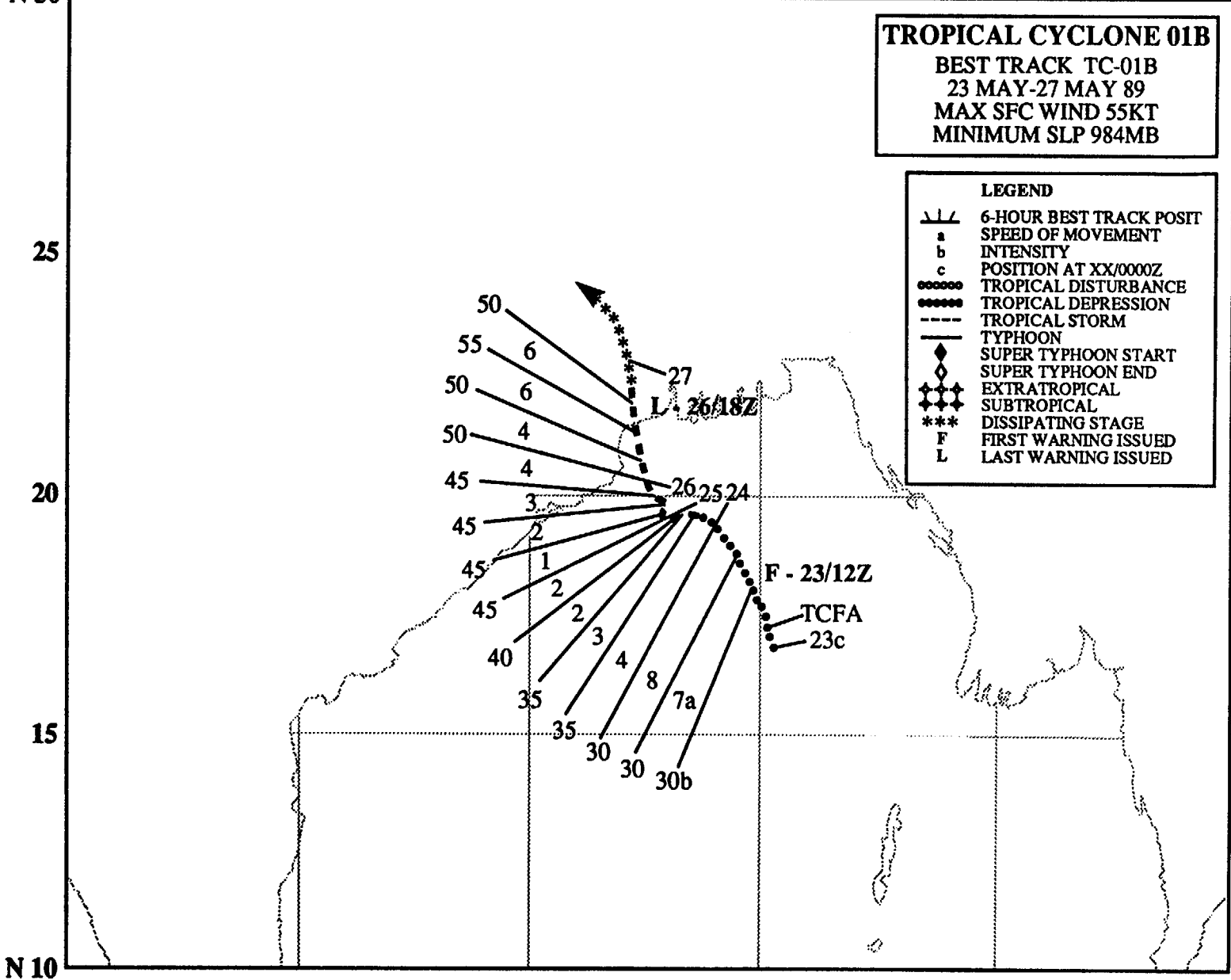
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TROPICAL CYCLONE 01B
BEST TRACK TC-01B
23 MAY-27 MAY 89
MAX SFC WIND 55KT
MINIMUM SLP 984MB

LEGEND

	6-HOUR BEST TRACK POSIT
a	SPEED OF MOVEMENT
b	INTENSITY
c	POSITION AT XX/0000Z
ooooo	TROPICAL DISTURBANCE
.....	TROPICAL DEPRESSION
-----	TROPICAL STORM
-----	TYPHOON
◆	SUPER TYPHOON START
◇	SUPER TYPHOON END
+	EXTRATROPICAL
+	SUBTROPICAL
***	DISSIPATING STAGE
F	FIRST WARNING ISSUED
L	LAST WARNING ISSUED

188



N 10

TROPICAL CYCLONE 01B

Tropical Cyclone 01B was the first of two cyclones to affect the Bay of Bengal and the only one to form in the Bay this year.

In mid-May, the monsoon trough was well-established throughout the Bay of Bengal between 8° to 10° north latitude with the heaviest convection persisting over the southwestern portion of the Bay. On 20 May, there was a broad area of poorly organized convection formed in the eastern half of the Bay and sparse synoptic data suggested a circulation center. But it wasn't until late on 22 May that the organization improved and convection increased dramatically. This development prompted JTWC to issue a Tropical Cyclone Formation Alert at 230330Z and the first

warning followed at 231500Z. The basic track to the north-northwest was interrupted on 24 and 25 May when weak mid-level steering resulted in an erratic and very slow movement.

Even though the system's development was slowed by northeast winds aloft, Tropical Cyclone 01B (Figure 3-01B-1) did attain a intensity of 55 kt (28 m/sec) at 261200Z, just before making landfall. After landfall the cyclone passed 60 nm (110 km) west of Calcutta, which recorded 25 kt (13 m/sec) sustained surface winds and a minimum sea-level pressure of 988 mb. Then, the dissipating circulation tracked northward into the heat low. No reports of damage were received.

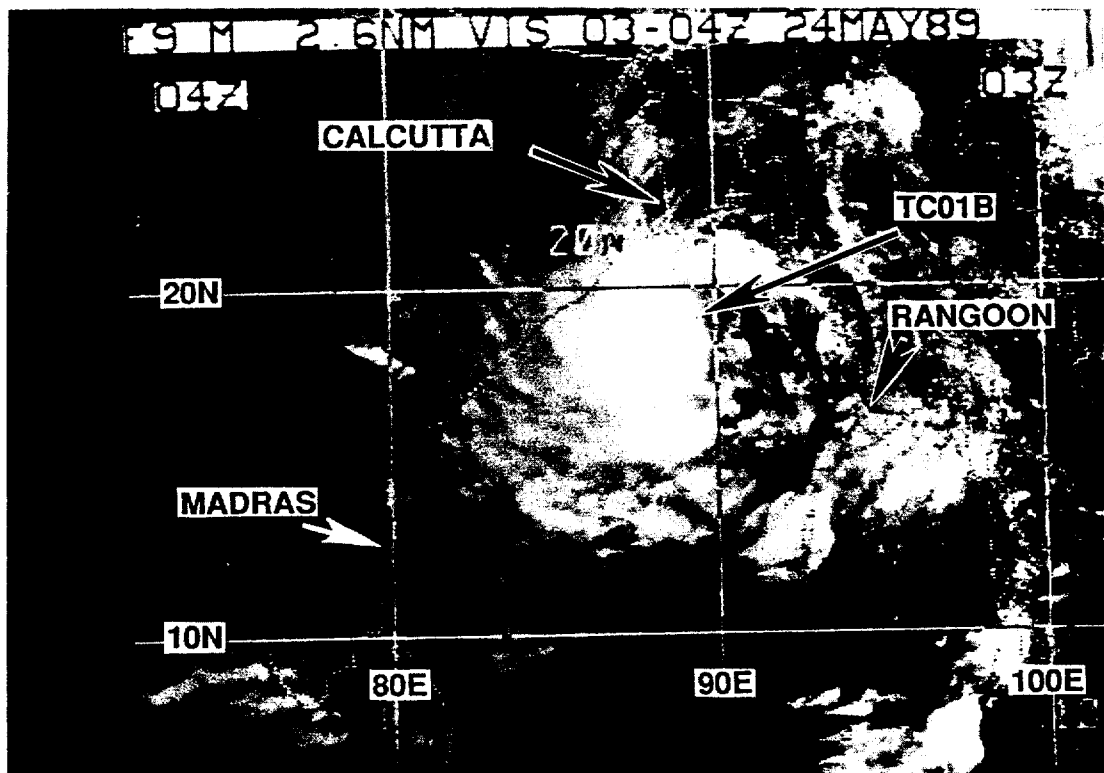
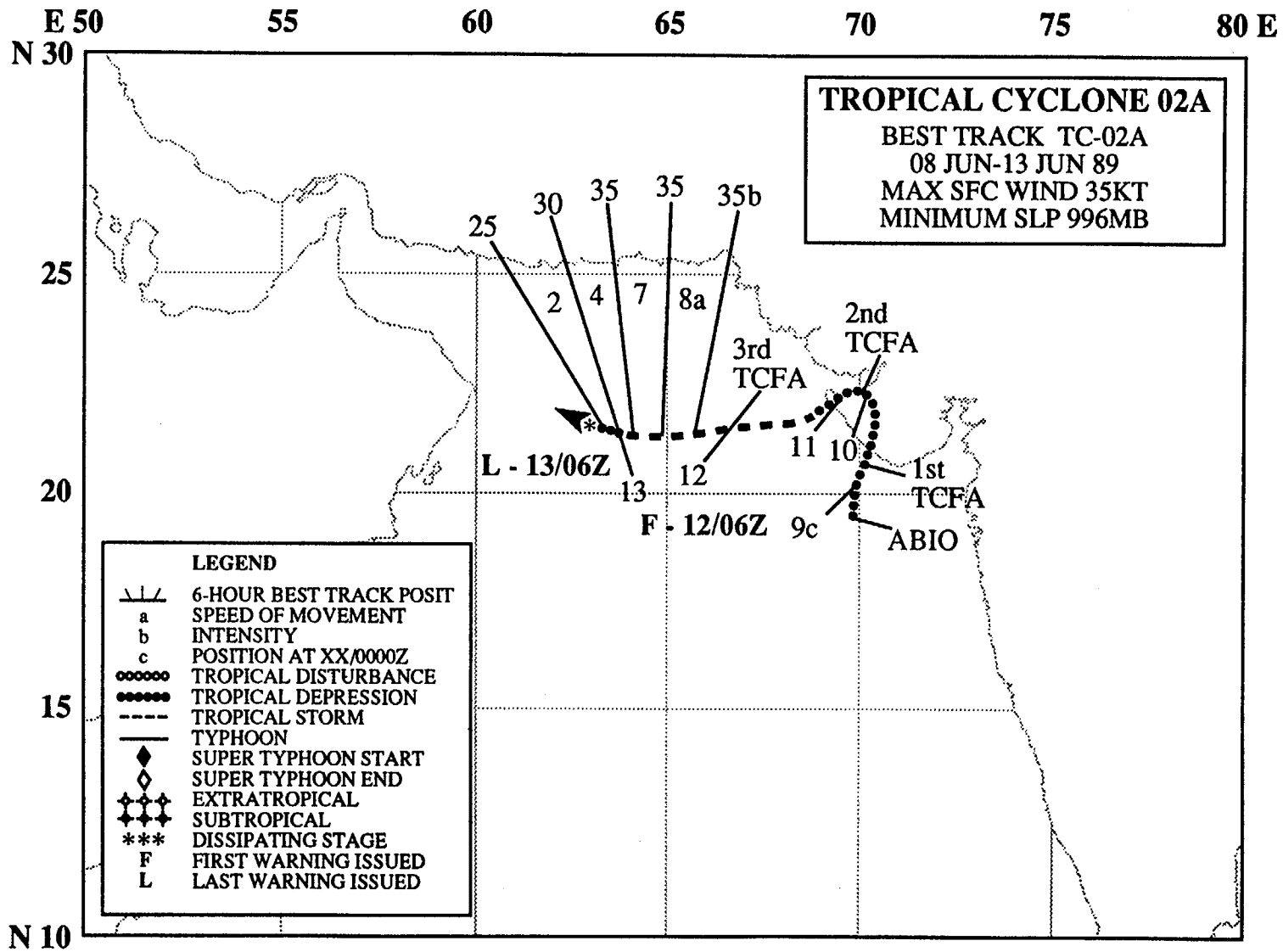


Figure 3-01B-1. Digitized mosaic from the satellite global data base at AFGWC shows Tropical Cyclone 01B moving towards landfall and Calcutta (240300Z-240400Z May DMSP visual data).



TROPICAL CYCLONE 02A

The only significant tropical cyclone to develop in the Arabian Sea this year, Tropical Cyclone 02A, generated from a pre-existing low-level circulation beneath an area of weak upper-level divergence. The disturbance was first mentioned at 071800Z June on the Significant Tropical Weather Advisory. Subsequent satellite imagery indicated the convection was organizing as it tracked toward the northwestern coast of India. The first satellite fix was made at 090148Z, and it estimated the intensity to be 25 kt (13 m/sec). This prompted JTWC to issue a Tropical Cyclone Formation Alert at 090600Z. Although a day later the circulation was technically overland, the presence of enhanced convection overwater resulted in reissuance of the Alert at 100600Z. This Alert was later canceled as satellite and synoptic data showed that the circulation had remained overland for more than 24 hours.

At 111629Z, satellite imagery (Figure 3-02A-1) revealed that the deep convection had moved rapidly westward into the Arabian Sea as an upper-level anticyclone advanced from the Arabian peninsula into Afghanistan and increased the eastern flow aloft over the Arabian Sea. A third Alert followed at 111800Z. Late arriving 110600Z ship observations reported 35 kt (18 m/sec) and a 998 mb pressure near the circulation center. Rapidly increasing convection and low-level organization led to an Abbreviated Warning at 120600Z. Mid-level flow around the subtropical ridge over Iran and Afghanistan carried the cyclone westward, but the strong northeasterly upper-level flow from the anticyclone aloft restricted its outflow and suppressed further development. The last warning was issued at 130600Z when satellite imagery indicated that the convection had separated more than 60 nm (110 km) to the west of the low-level circulation.

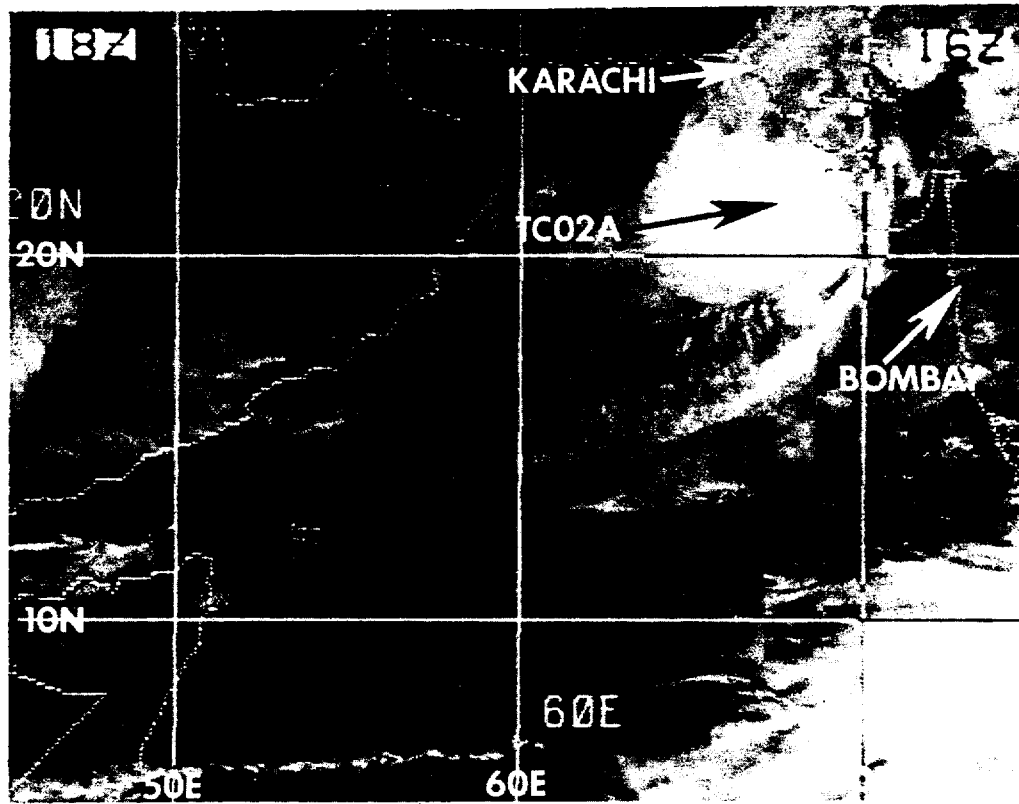


Figure 3-02A-1. A digitized mosaic of satellite data shows Tropical Cyclone 02A over the Arabian Sea (111600Z to 111800Z June DMSP infrared imagery).

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